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*Guided Missile Equipment Supplement*

# JET PROPULSION

STACKS

*Journal of the*

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*Rocketry . . . . Jet Propulsion Sciences . . . . . Astronautics*

VOLUME 25 — SEPTEMBER 1955 (In Two Parts) — SCIENCE AND TECHNOLOGY — NUMBER 9, PART 2

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TECHNICAL ARTICLES ON GUIDED MISSILE EQUIPMENT

# How to Tell a Story——*to an Engineer*

ENGINEERS are not like ordinary people, at least not while they are on the job. That is what makes the advertising problem so special for the manufacturer who plans to sell his product to the design or development engineer instead of to the ordinary public.

It is not that the engineer is a reluctant customer. On the contrary, he depends directly on the manufacturer of components for the success of his own company's production program, and is therefore ready to buy or specify the items his company needs. But, unlike the ordinary consumer, he will not buy or specify a particular component without first getting complete, authoritative, and quantitative information on its characteristics.

The problem is therefore one of providing an efficient means of communication, so that the component manufacturer can tell his story to the engineer faced with a design job and, equally important, so that the design engineer can get the information he wants when he needs it. Skillfully prepared advertisements, placed in engineering journals by experienced advertising agencies, are the usual medium for initiating communication between the purchaser and the manufacturer. But, as every engineer knows, an advertisement designed with the primary objective of catching the reader's attention rarely conveys actual performance data and almost never gives enough detail about the manufacturer's experience and reliability record. Limitations of space force the message to be short—frequently too short.

The editors of JET PROPULSION, who have had long experience themselves as practical engineers in the guided missile industry, have felt the need to try another solution to this communications problem, not to replace conventional advertising (which will always remain the principal channel) but to supplement it. We have come up with this idea: Let each manufacturer have enough space to tell his story in a more complete way in the form of a technical article about his products. Let it be written as a message from one engineer to another, in the language that they both know how to use best, namely, technical language. This Supplement on Guided Missile Equipment emerged from this idea.

We believe this issue represents a successful experiment in technical advertising and that it provides a service of benefit to each of the three parties concerned. The manufacturer pays for his space at a rate much less than that for ordinary advertising, and his message is placed in a special issue that will be kept close to the designer's desk for repeated reference until it becomes obsolete. The ARS benefits from this arrangement, since the revenue is more than enough to meet the costs, and the surplus can be used to finance other professional activities of the Society. Last, but not least, the individual member gets the kind of comprehensive engineering information regarding the products of prominent manufacturers that he likes to have at hand in ready reference form.

The success of this experiment has resulted in the formulation of a long range plan to publish this type of issue next year, and once a year hereafter. The guided missile industry depends for its continued progress on the specialized talents of hundreds of manufacturers of component devices. Any means to facilitate the introduction of their products and services into the projects that can utilize them constitutes a valuable service in the national interest, and the ARS is proud to be doing its part.

The editors wish to call your attention to the list of distinguished companies on the front cover whose articles appear in this issue. All the articles are worthy of study, for they contain information of potential importance to you or your colleagues.

To the hundreds of ARS members who have written to us and who have buttonholed us at ARS meetings to urge us to publish a special issue for designers: Here you have it!

**Martin Summerfield**
***Editor-in-Chief***

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# Temperature and Pressure Measurements

MARVIN SCADRON

**Aero-Research Instrument Company, 1040 West Grand Avenue, Chicago 22, Illinois**

IN testing research aircraft, knowledge of the conditions of the gas passing through or emerging from the aircraft's engine is necessary to compute the engine's performance. Similarly, in the operational engine these factors are also important for purposes of safety commensurate with maximum performance.

Factors of interest are total pressure, static pressure, flow angles, turbulence, pulsating flow (rotating stall and compressor surge), total gas temperature, liquid temperature, surface temperature, and free air temperature. Many elements have been devised to sense these factors, with varying degrees of success. This paper will discuss some of the more interesting probes that are manufactured by the Aero Research Instrument Company for the above purposes.

A simple water-cooled total pressure rake for measuring total pressure distribution in an afterburner or ramjet is shown in Fig. 1. Rakes of aluminum stainless steel or brass have been made.

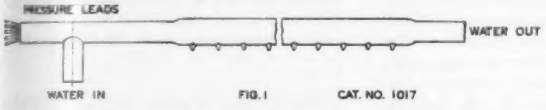



FIG. 1 CAT. NO. 1017

For cases where water cooling is not practical, short uncooled rakes made of a special high temperature material have been continuously used at 3000 F for 50 hours.

This probe will be very applicable for use with pressure ratio indication systems. Aero-Research has several designs of static pressure probes and directional probes, which have all been previously described in other papers. These are available upon request.

Turbulence and pulsating flow are usually sensed with hot wire anemometer systems. The most recent definite advancement in this field is the constant temperature type system. This has the advantages of being completely automatic in operation and compensation, having no wire burnouts and low noise level, requiring no batteries, and having an output signal proportional to the fourth root of the flow level at all frequencies. There is no attenuation of the signal due to improper compensation as occurs in the constant current systems. Aero-Research has two complete constant temperature systems with the following specifications:

| | Freq. resp. amp. | Freq. resp. probe & amp. | Equiv. noise level, % turb. level | Cat. no. |
|---|---|---|---|---|
| No. 1 | dc to 100,000 cps | dc to 60,000 | 0.05 | 1052 |
| No. 2 | dc to 20,000 cps | dc to 1,000 | 0.15 | 1053 |

The problem of surface temperature measurements has been solved through the use of swaged MgO insulated thermocouple wire (Fig. 2) as manufactured by Aero-Research Instrument Co. The sheath is attached to the surface and acts as the supporting member for the rest of the wire.

Hot liquid sodium measurements have been successfully made through the use of swaged MgO insulated chromel-alumel wire, where the junction is welded into the tip. The probe is inserted into the liquid through a compression type fitting.

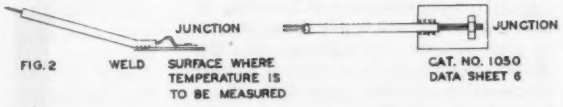



FIG. 2 CAT. NO. 1050 DATA SHEET 6

LOX measurements have been very successfully made with special thermistors and swaged MgO insulated conductors.

A universal type thermocouple probe is available for measurements in fuel, hydrogen peroxide, LOX, liquid nitrogen, liquid sodium, gas generators, and oil—all welded, stainless steel, with junction fully enclosed, but electrically insulated from shield. It has an extremely fast time constant (0.3 second at a Mach of 0.5 and pressure of 2 atmos). It can be cleaned without damage to the junction.

Free air temperatures are measurable with the use of a stagnation resistance thermometer. This thermometer has recovery factor of unity at all airspeeds and altitudes. It has a time constant of 0.25 second at Mach 1.5 and altitude of 10,000 feet. The unit can be boom mounted or mounted on an arm. This is Aero-Research Instrument Co. catalog no. T–1086.

Measurement of the total temperature of high temperature gas streams has been obtained through different types of probes depending upon the temperature level. For temperatures around 2000°F and less, the subsonic shielded aspirating probe (cat. no. T–1006) has been used. A pressure drop of 10 per cent through the shield will yield $1/4$ per cent accuracy. This probe has been successfully used in jet engine tailpipes where very accurate total temperature measurements were necessary. It has a time constant of one second at 6 lb./sec ft$^2$ of gas flow.

This same probe made with our high temperature metal, platinum—platinum-rhodium thermocouple wire, and zirconia insulation (cat. no. T–1006A) has been used successfully at gas temperatures of 2800 to 3000 F. This is probably the only uncooled probe that has been used to measure afterburner temperatures with negligible error and considerable life.

For gas total temperatures greater than 3000 F, three different techniques have been employed. The first technique involves the use of iridium—iridium-rhodium thermocouple wire in a cooled support. This wire has a melting point of about 4200 F and has a fairly long life in exhaust gases This probe has considerable conduction and radiation errors, and the results are only accurate to about 10 per cent if not corrected for the above-mentioned errors. This probe is Aero-Research cat. no. T-1625. This second technique involves the use of a multiple junction platinum—platinum-rhodium thermocouple wire in a cooled support (Aero-Research cat. no. T-1105). The multiple junctions yield sufficient information so that proper conduction corrections, as well as radiation corrections, can be simply made. Tests in afterburners show that accuracies of $1^1/_2$ per cent to 2 per cent in total temperature measurements are easily obtainable after correction. The third technique involves the passage of a portion of the gas through two sonic flow orifices in series (Aero-Research cat. no. 1065). By noting the total pressure in front of each orifice and the temperature at the second orifice the total temperature is readily obtainable. This probe has been successfully used to measure temperature distribution in rocket chambers.

*(Continued on page 45)*

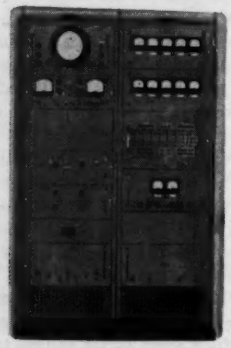
# Pulse Width Data Systems

**THOMAS S. MEDEROS, JR., Sales Manager**

**Applied Science Corporation of Princeton**

**Princeton, New Jersey**

A PW data system is a grouping of equipment which uses the techniques of time division multiplexing and Pulse Width coding to put a number of voltages representing physical quantities, into a form which permits transmission over a single circuit or link, or recording on a single channel or track. The system also provides for the separation and identification of the previously multiplexed data channels and decoding back into voltages, which are used to provide visual display, graphic records, input to data processing equipment or control functions.



**M SERIES PW GROUND STATION**

**Separates and reduces all data channels in real time. Operates on signals from standard airborne set, FM/FM subcarrier, or magnetic tape recorder.**

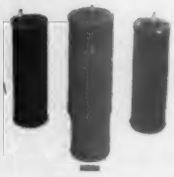
In a PW system, the intelligence is conveyed by the pulse duration rather than amplitude, and therefore the transmission medium is not required to have amplitude linearity but only the ability to discriminate between two states which may be called "on" and "off" or "mark" and "space."

## Operation

The basic functional units required in any PW system are transducers, a commutator with suitable driving device, a keyer, an RF transmitter, and data reduction equipment for converting the PW data signals into usable form.

Since the PW data system requires that input signals should be in the form of voltages, suitable transducers capable of converting physical quantities into voltages are used. Present ASCOP PW multicoders operate from signals in the range of 0 to +5 volts, but low-level equipment will be available in early 1956 with sufficient sensitivity to accommodate inputs in the low millivolt range.

The time division multiplexing is accomplished by a motor-driven rotary sampling switch or commutator. Standard sampling rate is 900 samples per sec, and commutators are now available for operation at 30 RPS over 30 points, 20 RPS over 45 points, and 10 RPS over 90 points. Since two points of the commutator in any of the systems are left unconnected, to provide a gap in the pulse train for "frame" identification, the existing numbers of channels available for data and references are 28, 43, and 88, respectively.



**F SERIES MISSILE SETS**

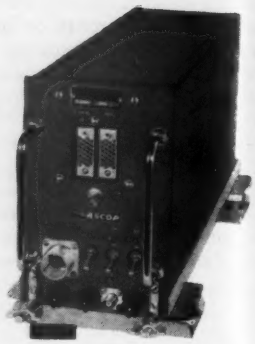
**Samples up to 43 data sources. This rugged equipment is sealed and pressurized to withstand high altitudes, operation and temperature extremes.**

System linearity is determined by the transfer characteristic of the keyer, from volts to Pulse Width, and the linearity of the translator back into volts. A typical ASCOP Pulse Width data system does not deviate from linearity between the scale end points, by more than 0.5 per cent. The total system drift, from any cause, is less than ±0.5 per cent of full scale. Since system levels are maintained by an automatic electronic servo, this degree of stability is maintained over periods of days or weeks, and is accomplished without any warm-up time.

With the stairstep type of electrical output provided by the M Series ground station, it is generally conceded that 6 samples per cycle of the highest data frequency component present allow visual interpolation of output records to better than 1% accuracy. This means that any channel of a 30 × 30 system can reproduce 5 cps data. The frequency response of one or more data channels in the system can be increased by a factor of 2, 3, 4, or more by increasing the effective sampling rate. This can be accomplished by applying the same transducer output to a corresponding number of commutator contacts, and making similar provision during decommutation.

**SPECIAL MISSILE SET**

**ASCOP-designed for a customer.**



**D SERIES PW MULTICODER**

**For aircraft, mobile or other applications where recovery or continued use is practical and where space and weight are not critical. Samples up to 43 data sources.**

## Uses

At present, most PW data systems are used for recording experimental test data from missiles and aircraft, where hazard, space limitation, and volume of data to be gathered make the use of a human observer impossible. Measurements of such quantities as the temperature, pressure, strain, altitude, acceleration, flow rate and position are made at rates thousands of times faster and much more accurate than could be done by visual observation and manual recording.

Additional application is also found in experimental test work where hazard and space are not limitations, but where the total volume of data require both high speed automatic measurement and recording. Engine test stands, reactors, and complex electronic equipment are typical devices whose testing requires the automatic measurement and recording of large numbers of physical properties.

PW data systems have been used where many measurements must be transmitted and displayed in easily interpreted form, as in the case where a pilot on the ground must rely on display instruments while he controls a drone aircraft, or in the case where the flight test engineers on the ground must observe conditions in a piloted aircraft in order to insure the safety of the pilot.

ASCOP
WE PROVIDE THE LEVER • YOU MOVE THE WORLD

# SR-4—PTL—ICBM

H. A. NIELSEN, Baldwin-Lima-Hamilton Corporation

THE title of this article looks like a formula expressing some physical or chemical relationship. In fact it almost is, though it actually represents a composite of trade and armed services jargon which illustrates in somewhat crude fashion the very close relationship and important function the bonded wire resistance strain gage principle in its various forms, as manufactured by Baldwin, has played in the Guided Missile development program. Defined, the formula breaks down as follows:

SR-4—Trademark of the bonded wire resistance strain gage principle, primarily developed by E. E. Simmons of California Institute of Technology, and A. C. Ruge of Massachusetts Institute of Technology, and their respective associates, D. S. Clark and A. V. Deforest. Hence, SR-4—Simmons, Ruge and a total of four people are responsible for the basic concept.

PTL—Trade parlance for the variables that the SR-4 strain gage in its various applied forms, commonly measures—pressure, torque, or load.

ICBM—Armed forces terminology for the intercontinental ballistics missile, the development of which has required extensive use of the SR-4 principle in all phases of the program, from original concept to actual launching.

The purpose of this article will be to highlight some of the applications and uses of the SR-4 principle in the missile program, which have been many and varied, and to briefly cover some of their technical aspects.

The postage stamp strain gage itself, consisting of a fine wire filament, sandwiched between layers of paper or bakelite, and bonded with suitable cement to a structure, has been almost indispensable in obtaining basic design data on the strength of materials or structures under actual flight or loaded conditions from temperatures of −60 to +1800 F. There are approximately 150 standard strain gage types with which most engineers are familiar and have used since their original introduction to the market in the early 1940's. These gages faithfully follow static or dynamic strains at frequencies up to 50,000 cps or higher, at temperatures up to 350 F, at strains up to 3 or 4 per cent of their initial gage length. Since there is much published information on them, and knowledge on their availability and use is commonly known, we will discuss here some of the new types now available which perhaps are not so widely known.

The tendency in guided missile development has been to design more and more to ultimate strengths rather than yield strengths, since the philosophy is that a missile has generally a one-directional-flight life expectancy, and if the ultimate strengths are predictable and can be accounted for in the design, then the result is a missile of lesser weight and cost. However, most standard strain gages will only measure strains up to 3 or 4 per cent of their initial gage length before bond or sandwich failure occurs. This led to the development of the type PA-3 gage, which is similar to the standard paper type A-3 gage, but which uses a special stretchable paper and cement of similar characteristics, permitting measurement of strains up to 10 per cent of the initial gage length, in the post-yield region. As a result, this gage has played an important role in guided missile research where ultimate strengths have taken on new significance.

It is a common requirement of standard strain gages to use a "dummy" gage, subject to the same temperature as the active gage, but not to strain, to compensate for temperature effect on the active gage element. This becomes a considerable burden in many missile applications where there is is simply no room to locate a "dummy" gage, subject to the same temperature as the active gage, but to no strain. The self-compensated gage has been the answer to this problem. Some lots of gage wires show an apparent increasing strain with increased temperature and some show an apparent decreasing strain with increased temperature, and by careful selection of appropriate lengths of wire of each characteristic, and building these into the gage filament, it has been possible to construct a gage which will be essentially self-compensating for temperature and measure only strains due to stress when bonded to the material for which they are constructed. These gages have been available in several configurations, for use on dural, or steel, for about four years. They are available for the best fit about zero over two temperature ranges as illustrated in Figs. 1 and 2.

A new gage in this family is now being introduced, which is compensated for best fit over a temperature range of +50 to +250 F when bonded to quartz, which has essentially a zero temperature coefficient. Therefore, this gage when bonded to a temperature cycled, unstrained member of any other material will actually measure the strain due to thermal effect only, or when bonded to a loaded member, will measure strains due to both temperature and load.

Another new type in this family is now available for use on titanium.

Considerable research has been devoted to gages that will reliably reproduce strains at temperatures above 350 F, and a trial kit is now available containing gages that have been used satisfactorily at temperatures up to 1800 F. The kit includes ten foil type gages and several ceramic type cements, for use at various temperature ranges. One of these will cure at room temperature and can be used up to 700 F. There is still much work to be done on these gages, before they become the tried and proved product in the many

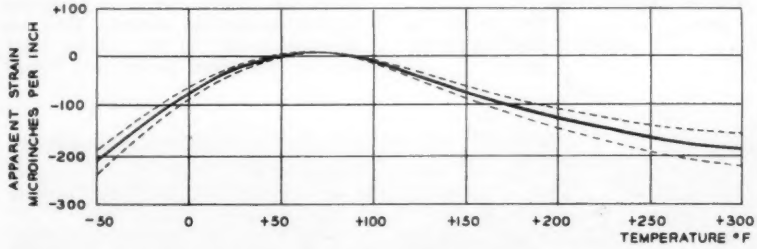



Fig. 1 Compensated for best fit from −50 to +300 F. Dotted lines show normal spread. Typical curve

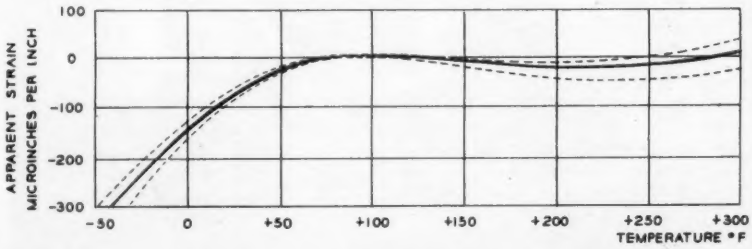



Fig. 2 Compensated for best fit from +50 to +250 F. Dotted lines show normal spread. Typical curve

configurations of the standard SR-4 line, but present progress is promising.

Printed circuit foil type gages are now also available in kit form, and the superior fatigue life of this type of gage is one of their outstanding features, as well as the technique of manufacture, which lends itself to mass production and perhaps ultimately, more inexpensive gages.

Another phase of the role of SR-4 in missile development is the use of SR-4 transducers, for direct, accurate indication of pressure, torque, or load.

SR-4 pressure cells have been used for measurement of various pressures in both liquid and solid fuel propellant rocket development. They are perhaps unique in the pressure measuring field in their precision of pressure indication, most of them having a calibration accuracy of $\pm 1/4$ per cent of capacity and a maximum nonlinearity of $\pm 1/4$ per cent of full capacity of best fit line. They are available in various configurations in standard capacities from 15 psi to 50,000 psi. A typical specification of a standard 20,000 psi tubular type cell follows:

| | |
|---|---|
| Calibration accuracy | $\pm 1/4$ per cent of full capacity at 70 F |
| Linearity | $\pm 1/4$ per cent of full capacity of best fit line |
| Internal volume | 0.64 cubic inch |
| Nominal full scale output | 1.000 millivolt per volt input at 70 F |
| Recommended supply voltage | 6 volts (10 maximum) AC or DC |
| Input bridge resistance | 120 ± 0.5 ohm at 70 F |
| Temperature effect on sensitivity | 0.005 per cent of reading per degree F |
| Temperature effect on zero | 0.005 per cent of capacity per degree F |
| Overload guarantee with no adverse effects or zero shift | 120 per cent of capacity |
| Factory overload test | 200 per cent of capacity |
| Natural mechanical frequency response | Above 20,000 cps |

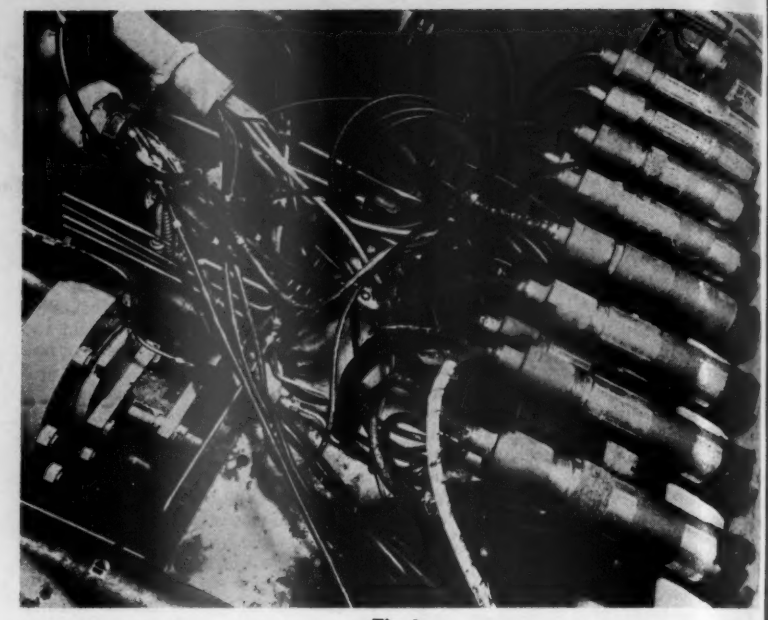


Fig. 3

Pressure cells have been built to measure rocket combustion chamber pressures, with water cooling, at temperatures up to 5000 F. A typical rocket test installation using SR-4 pressure cells is shown in the photograph in Fig. 3, which pictures a battery of cells under the most rugged vibration and service conditions.

SR-4 torque pickups are enjoying increasing usage in the testing of missile accessories such as centrifugal pumps, small gas turbine units, and various types of motors and starters. They are mounted directly in the driving shaft between the prime mover and driven unit, and are available in standard capacities from 100 in.-lb to 30,000 in.-lb at speeds up to 12,000 rpm, and special units have been built for speeds up to 25,000 rpm. A typical aircraft engine dynamometer setup is shown in Fig. 4, with the torque pickup mounted between the engine and the loading unit. These pickups also have the standard SR-4 degree of precision with $\pm 1/4$ per cent calibration accuracy.

For measurement of loads and missile thrust, the SR-4 load cell has perhaps been applied in the greatest variety of installations. Approximately 200 jet engine thrust and calibration systems are in service in semi-portable thrust stands

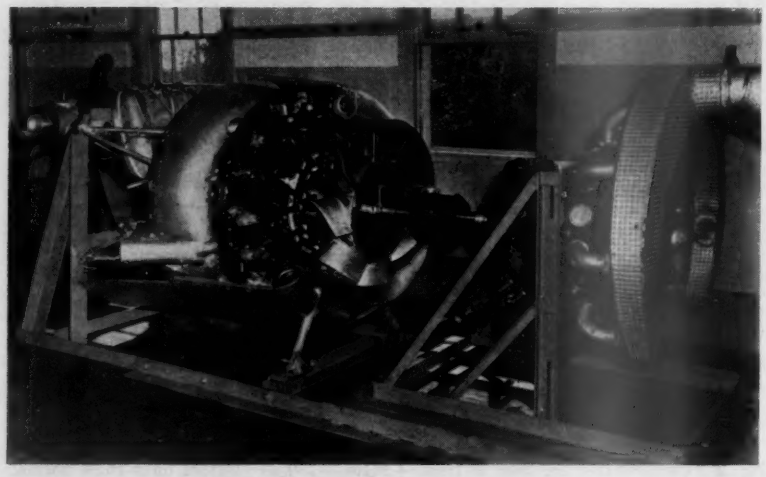


Fig. 4

Fig. 5

as shown in Fig. 5. Here the engine is rolled into the U-frame, which is supported on four vertical flex-plates, and clamped into position by four air cylinders. As the engine fires, the frame deflects against the SR-4 load measuring cell, located centrally and horizontally at the base of

the U-frame, and the cell output is fed into an automatic null balance indicator. Common thrust system accuracies are on the order of $^1/_2$ per cent of applied thrust down to $^1/_4$ scale. The SR-4 thrust system is in turn calibrated by an SR-4 calibration system, certified by the National Bureau of Standards. Load is applied to the U-frame with suitable jacking means, statically, in physical series with the calibration cell, the certified output of which is checked against that of the thrust measuring system. Guarantee on the calibration kit is $^1/_{10}$ per cent of reading down to $^1/_{10}$ per cent of scale, when used with the Bureau correction. The calibration kit is pictured in Fig. 6.

Typical characteristics of the standard SR-4 line of load cells are as shown in Fig. 7.

## Linearity

If a straight line is drawn connecting the cell output at zero load and the cell output at rated capacity on a mv/v versus load plot, the output curve of the cell (maximum nonlinearity) will be within the locus of points distant from the straight line by the following values:

| Type Load Cell | Capacity | Maximum Non Linearity (Percent of Full Scale) |
|---|---|---|
| U-1 | 50, 100, 200# | ± 0.20% |
| U-1 | 300, 500, 1000, 2000# | ± 0.10% |
| U-1 | 5000#, up | − 0 + 0.20%, compression* + 0 − 0.20%, tension* |
| C | All Capacities | ± 0.25% |
| CXX | 500, 1000, 2000# | ± 0.10% |
| CXX | 5000#, up | − 0 + 0.20%* |
| Load Beam | All Capacities | ±0.25% |

* For these cells the line connecting zero to F.S. is not the best fit straight line; therefore, higher linearities are possible.

**SR-4 Load Cells and Load Beams—Table of Accuracies Maximum Allowable Error in Per Cent**

| Function | Standard (Load Cell Types C, U-1, and Load Beams) | Extra Precision (Cell Type CXX) |
|---|---|---|
| Accuracy of full-scale output adjustment at 70°F | ±.25%* | ±.10% |
| Temperature effect from 15 to 115°F on sensitivity (output) | ±.005% of load per degree F | ±.0008% of load per degree F |
| Temperature effect on zero (15 to 115°F) | ±.0025% of full scale per degree F | ±.0015% of full scale per degree F |
| Zero balance at 70°F | Within 2½% of full scale | Within 2½% of full scale |

* Some capacities of U-1 cells apply only in tension service. Actual outputs for compression service are about 1.2 per cent lower. The exact full scale output in compression service is supplied with each cell.

**SR-4 Load Cell Characteristics Fig. 7**

**Fig. 6**

Similar thrust and calibration systems to those described for jet engines above, have been furnished for the static testing of large liquid propellant rockets, though, of course, these systems have much greater capacity, usually use combinations of several load cells with outputs electrically totalized for measuring thrust, generally utilize a vertical thrust structure, with instrumentation as much as 1000 ft away. Fig. 8 shows a general schematic arrangement of such a system. Individual cell capacities of up to 125,000 lb have been incorporated in these systems.

SR-4 load cells have also been used to weigh certain accessory tanks incorporated as part of a rocket test installation as described above, and more recently the calibration kit pictured in Fig. 6 has seen use as a portable field weighing kit for weighing missiles prior to launching.

Certainly, from just the few highlights mentioned above, the symbolic configuration "SR-4—PTL—ICBM" will be appreciated as having quite a significant relationship, if not altogether precisely mathematic.

**Baldwin-Lima-Hamilton Corp.**
**Philadelphia, Pa.**

**VERTICAL ROCKET THRUST STAND THRUST AND CALIBRATION SYSTEMS**

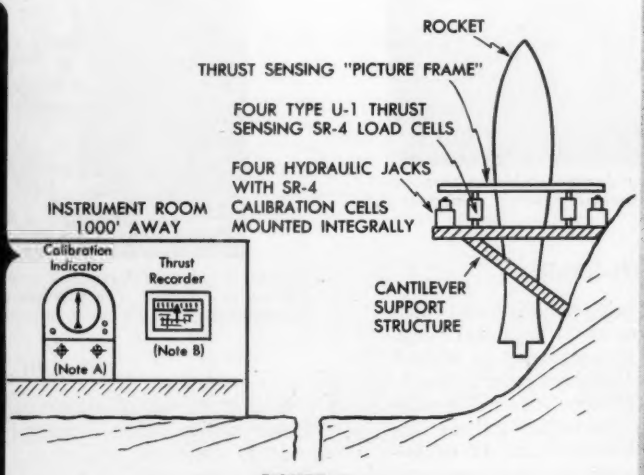



**FIGURE 8**

**Note A**
Pumping unit in base cabinet actuates jacks on thrust stand to apply static load measured by calibration cells whose output is fed into 24" diameter dial on upper half of base cabinet, combination of cells and indicator previously calibrated by National Bureau of Standards.

**Note B**
Thrust recorder indicating totalized firing; thrust sensed on four type U-1 cells.

# Making a Guided Missile

**D. M. HELLER, Director of Engineering**

**BENDIX PRODUCTS DIVISION—MISSILES, BENDIX AVIATION CORPORATION, Mishawaka, Indiana**

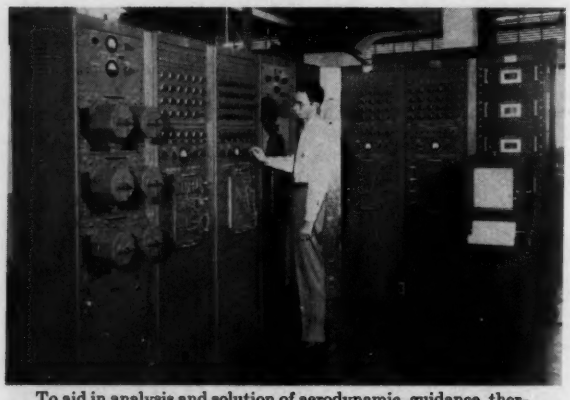
*The strict security surrounding our project prevents the use of other descriptive photographs, curves, and technical data which would add much to this paper. However, we believe sufficient material has been released to permit a general description of the problems of making a guided missile.*

## Systems Analysis

ANY missile may be thought of as consisting of three major systems—a structural skeleton or airframe system, an engine or propulsion system, and a brain or guidance system. Accordingly, the effort in Systems Analysis is concerned with the over-all dynamic behavior of missiles and weapon systems and with the actions and interactions of the three basic systems particularly in terms of weapon performance.

The techniques used in obtaining these results involve conventional analytical methods, simulation of actual problems and various experimental methods. The basic tools for performing these operations are an extensive electronic analog computer facility, breadboards and prototypes of actual missile equipment, and various special mechanical and electronic simulators. On occasion, certain specialized problems require the use of high speed digital computers and wind tunnel facilities.

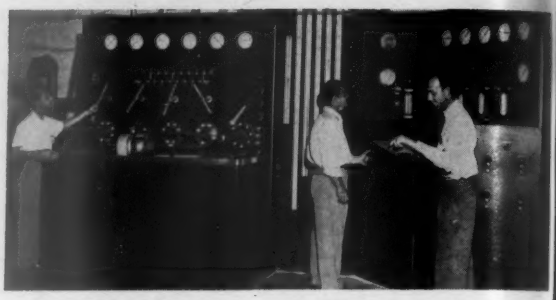
The fundamental problem is one of analytical dynamics. However, many familiar fields of science such as aerodynamics, servomechanisms, ballistics, computing techniques, electronics, fluid mechanics, heat transfer, microwaves, stress analysis, shock, thermodynamics, and vibrations are also invaded in solving these problems.



To aid in analysis and solution of aerodynamic, guidance, thermal, and performance evaluation problems, Bendix employs the electronic analog computer.

## Propulsion and Hydraulics

The vehicle must be capable of being propelled with specified velocity programs over ranges up to maximum range. This mechanism, like all missile systems, must be efficient and reliable, and still represent an optimum compromise between weight, volume, and cost. This system must be so designed as to make the most efficient use of the fuel selected. The control system of most missiles utilizes an electro-hydraulic servomechanism. Such systems must be integrated with the other missile systems.

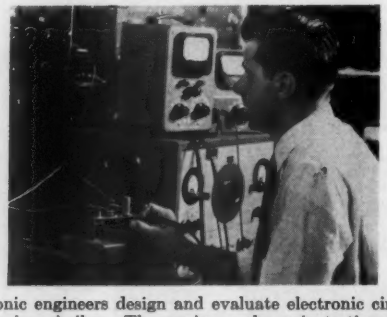


Propulsion system engineers at the Missile Section check out distributor valves using the facilities of a specially designed high capacity fuel flow bench. It is capable of flowing fuel at rates up to 450 gallons per minute at pressures of 250 pounds per square inch. Also, air flows of 2 pounds per second at 100 pounds per square inch absolute pressure can be attained.

## Guidance

The brain of a guided missile is the electronic guidance system. It is the mechanism which receives, interprets, and acts on information from the outside and from its own corrective or feedback devices. The "act-on-information" equipment is the autopilot or control system. This airborne electronic equipment must give top performance yet withstand severe punishment, be light in weight, and small in size. Rugged equipment is normally heavier than standard, and the solution of problems resulting from these conflicting criteria challenges the ingenuity of capable engineers.

Electronic engineers are responsible for the design and evaluation of control systems, including airborne power supplies, connecting wiring, and cabling. Specialized test equipment must be designed and used for "dry runs" of airborne devices. Every missile system and component must be thoroughly checked for performance before it can be labeled "flyable" and approved.



Electronic engineers design and evaluate electronic circuitry for use in missiles. The engineer above is testing breadboard circuitry using a meter for phase checks.

## Design

Several groups at the Missile Section concern themselves with coordination problems. Coordinating the effort of many agencies in the missile program is a problem of large magnitude. Engineers with experience in the design of industrial products and test equipment prepare layouts for each system

of the missile. Problems of performance, fabrication, and installation constantly require new designs to improve the missile.

The design engineer and the skilled draftsman shown here discussing an internal modification, are part of a closely knit team whose assignments demand an intimate knowledge of all missile systems.

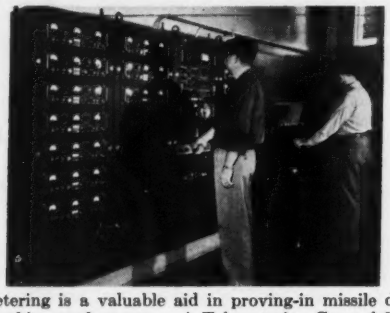
## Component Evaluation

Every component that goes into a missile must meet exacting specifications within very close tolerances. One of the important duties of the engineers in the component evaluation group is the work of testing many different components in order to find those that are suitable for use in a missile. Some technicians are also assigned the responsibility of testing every tube used in the electronic parts of a missile. Special tube checking equipment for this work has been built to specifications. Components to be evaluated are given exhaustive tests to determine how they will react to shock, vibration, heat, cold, high and low voltages, storage, acceleration, altitude, and humidity.

The microscopic evaluation of tubes determines to a large extent the suitability of tube types for use in guided missiles. The tubes shown have undergone intensive vibration testing. They will be examined for possible internal damage.

## Telemetering

Telemetering is widely used today in the field testing of every important missile program. While telemetering systems are available from several manufacturers, the particular system used must be closely integrated with the other electronics of the missile. The telemetering group determines the instrumentation necessary to record voltages, accelerations, pressures, and strains. The group is also responsible for the design and testing of end instruments and the operation of the ground station.

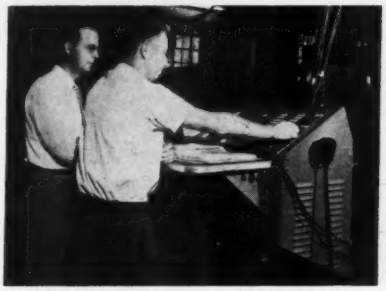


Telemetering is a valuable aid in proving-in missile designs and checking performance. A Telemetering Ground Station is shown in operation.

## Missile Testing

The various component systems are tested while operating in a missile. Missiles are tested in both simulated and actual test flights. Performance data are gathered by automatic recording devices for comparison with theoretical predications.

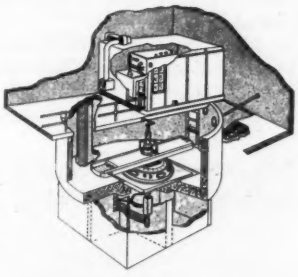
Data accumulated in missile testing serve as a guide for future design and record progress of missile technology.



Members of a Missile Test crew are shown operating a console which programs various phases of simulated missile flight.

## Environmental Testing

An environmental test laboratory complete with centrifuge, altitude chambers, shake devices, and impact testers subjects missiles and components to every probable condition of altitude, temperature, humidity, impact, vibration, and acceleration.



The cutaway sketch (right) shows the large centrifuge, which is used to accelerate missile subassemblies to seventy-five times the acceleration of gravity.

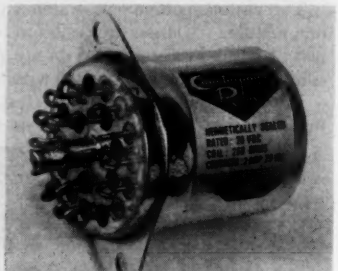
**UNITED STATES NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT Operated by Bendix**

# A Relay Design for Jet and Rocket Circuits

DANIEL SHEVELENKO[1]

Cook Electric Company, Chicago 14, Ill.

MANY of the relay requirements for jet and rocket applications parallel the increasingly severe specifications being written for relays used in conventional aircraft. These include: higher temperature requirements (125 deg C at present but up to 600 deg F in sight); the increased requirements for higher frequency vibration, first to 500 cycles per second, 10 g, then to 2000 cycles per second at 15 g; a concern with high impact and high acceleration; an insistence on size and weight reduction.

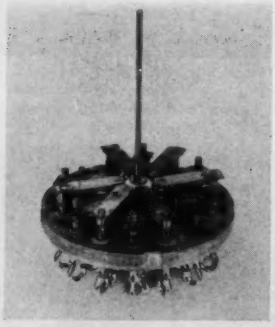


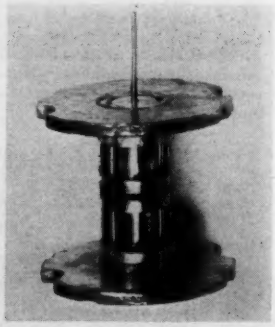
Counterpoise relay

Probably the two outstanding needs in the present jet and rocket circuitry are higher reliability and dry circuit operation. The high reliability is partially needed because there is no room for redundancy in present designs and, of course, there is no manual override. One calculation on a typical application indicated that one failure in 10,000 on any of the relay links would make the missile only 85 per cent reliable. The dry circuit problem is serious because a missible may be stored for several years and then call on each component to operate faultlessly on the first try. Slight contact contamination of any sort could be fatal both literally and figuratively.

An outstanding development in the present attempt to meet these difficulties has been the 6 P.D.T. relay originally proposed to industry by Wright Air Development Center. The relay, illustrated in the accompanying photograph, was designed to meet the compactness, light weight, and multiple circuit requirements of the various switching circuits envisioned in these designs.

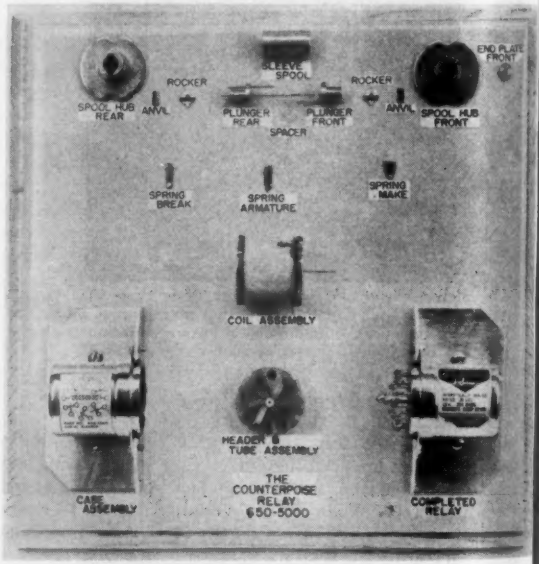
Many ingenious mechanisms were engineered to meet these specifications. It soon became apparent that two basic difficulties faced the designer. In a solenoid mechanism, the plunger would become resonant somewhere within the critical vibration frequency range, resulting in either mechanical failure or considerable chattering of contacts. In the case of rotary designs, either because of the space configuration difficulties or due to power loss from flux leakage and other limitations, these designs were largely made using low contact pressures and small contact gaps. These in turn led to poor performance under shock and vibration.





Microscire assembly sectional view of actuator

Probably the outstanding relay advance in the past fifty years, a rather venturesome step away from conventional armature type, clapper, or solenoid designs, was the relay invented by the W. N. Borg Corporation. This relay retained all the advantages of the solenoid design, with pole faces located in the center of the coil to give high power and low leakage flux. Approximately 80 per cent of the total volume is occupied by the coil to insure high operating force, high gram pressure, and a large contact gap. The case itself is part of the magnetic circuit. The principle, now tested and in volume production by the Cook Electric Company, Chicago, Ill., is known as the Counterpoise relay. The standard design has been completely checked to MIL-R-5757B specification.




650-5000 Counterpoise relay exploded view

The Counterpoise advancement incorporates the principle of the fulcrum and the lever. When two balanced weights act in the same direction and at equal and opposite distances from the fulcrum, no motion can take place. This is the case encountered when the relay is subjected to either shock or vibration. However, when the coil is energized and de-energized, a force couple is produced giving the lever a smooth, rocking motion which is transmitted to the relay contacts. Therefore the entire relay mechanism is responsive to electrical energy only.

As a special bow to the missile requirements, several fea-

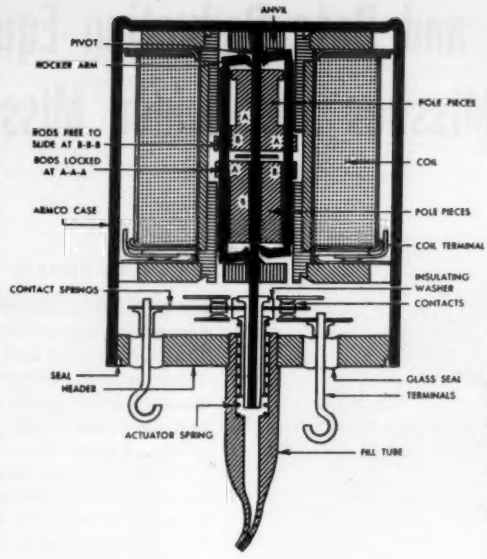
[1] Manager of the DIAPHLEX Division.

tures were incorporated in this design to give the highest possible dry circuit reliability. These include the use of nonvolatile materials. While the coil uses such materials as enamel, teflon, and fiberglas, the dry circuit version of the Counterpoise relay has the coil winding completely sealed off from the contact area. The contact assemblies themselves depend on no separators but are suspended directly from the glass insulated terminals. No soldering, brazing, or any type of flux has been used in the assembly to assure complete absence of volatile materials.

An additional feature of this unit is the use of low surface resistivity, noble metal contacts to give high reliability even with millivolts of potential and micro-amperes of current.

Still a third feature is the evacuation tube in the center of the relay. This allows a careful degassing, testing with helium indicator with a mass spectrometer, and final fill with dry nitrogen gas.

An accompanying table lists the present features of this relay. Several versions are indicated. The standard relay can be made for either 85 deg C or 125 deg C operation. The relay may have two ampere regular contacts or milliampere dry circuit contacts. Also relays are available for either 10 to 500 cycles per second to 2000 cps operation.




Relay manufacturers are currently too small a group to influence basic material developments by the larger corporations. However, they have pioneered in the use of new materials as they have become available.

Magnet wire can now be purchased for 600 deg F applications. Old standbys such as phenolic and vinyl insulation have given way to new, less volatile materials.

The real change in design approach lies in the attitude that conventional relay practices are no longer adequate; that improvisation and modifications will no longer serve; that entirely unique mechanisms must be devised as the only way of continued advancement in the field.

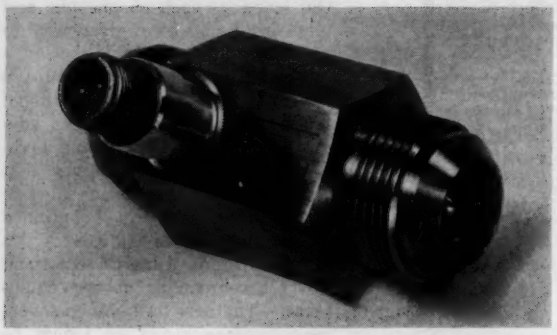
A final result of the present trend is the mushrooming of test equipment. The new tests are so severe that a designer can no longer be sure that he knows the right answers, and a long arduous test program must accompany every new relay development.

With the other firms presently engaged in this complex field, we find a considerable challenge in the present requirements. No relay design, no matter how good, can ever be the final word where Mach 10 flight is being seriously discussed. Cook Electric Company is proud to be sharing in this challenge and adventure.

**Table 1 Typical Operating Data**

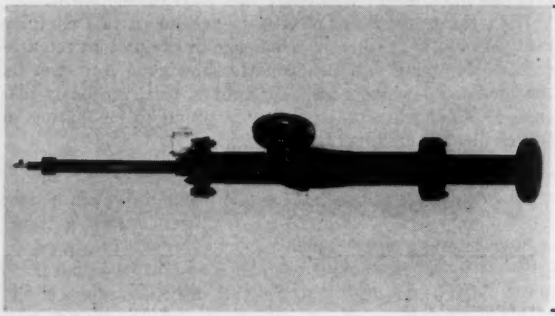
| Part Number → | 650-5000 | 650-5161 | 650-5005 | 650-5162 | 650-5092 | 650-5163 | 650-5160 | 650-5164 |
|---|---|---|---|---|---|---|---|---|
| Maximum operating volts | 29.0 VDC | 29.0 VDC | 29.0 VDC | 29.0 VDC | 29.0 VDC | 29.0 VDC | 29.0 VDC | 29.0 VDC |
| Pick-up volts 20 C | 14.0 VDC max. | 14.0 VDC max. | 14.0 VDC max. | 14.0 VDC max. | 14.0 VDC max. | 14.0 VDC max. | 14.0 VDC max. | 14.0 VDC max. |
| Drop-out volts 20 C | 4–8 VDC | 4–8 VDC | 4–8 VDC | 4–8 VDC | 4–8 VDC | 4–8 VDC | 4–8 VDC | 4–8 VDC |
| Rated load | 2.0 amp 28 VDC Resistive | 2.0 amp 28 VDC Resistive | 2.0 amp 28 VDC Resistive | 2.0 amp 28 VDC Resistive | Low current & volts (Dry ckt.) | Low current & volts (Dry ckt.) | Low current & volts (Dry ckt.) | Low current & volts (Dry ckt ) |
| Operating cycles | 100,000 | 100,000 | 100,000 | 100,000 | 100,000 | 100,000 | 100,000 | 100,000 |
| Maximum weight | 0.22 lb | 0.22 lb | 0.22 lb | 0.22 lb | 0.22 lb | 0.22 lb | 0.22 lb | 0.22 lb |
| Contact gap | 0.008 in. min. | 0.008 in. min. | 0.008 in. min. | 0.008 in. min. | 0.008 in. min. | 0.008 in. min. | 0.008 in. min. | 0.008 in. min. |
| Rated duty | Continuous | Continuous | Continuous | Continuous | Continuous | Continuous | Continuous | Continuous |
| Nominal coil volts | 26 VDC | 26 VDC | 26 VDC | 26 VDC | Millivolt range | Millivolt range | Millivolt range | Millivolt range |
| Ambient temperature | −55 C +85 C | −55 C +85 C | −65 C +125 C | −65 C +125 C | −55 C +85 C | −55 C +85 C | −65 C +125 C | −65 C +125 C |
| Coil resistance ± 10%, 20 C | 260 ohms | 260 ohms | 260 ohms | 260 ohms | 260 ohms | 260 ohms | 260 ohms | 260 ohms |
| Contact arrangement | 6 PDT | 6 PDT | 6 PDT | 6 PDT | 6 PDT | 6 PDT | 6 PDT | 6 PDT |
| Vibration | 10–500 cps 10 g | 10–2000 cps 15 g | 10–500 cps 10 g | 10–2000 cps 15 g | 10–500 cps 10 g | 10–2000 cps 15 g | 10–500 cps 10 g | 10–2000 cps 15 g |
| Shock | 50 g, 11 ms. | 50 g, 11 ms. | 50 g, 11 ms. | 50 g, 11 ms. | 50 g, 11 ms. | 50 g, 11 ms. | 50 g, 11 ms. | 50 g, 11 ms. |
| High potential ground test | 1000 VAC Rms | 1000 VAC Rms | 1000 VAC Rms | 1000 VAC Rms | 1000 VAC Rms | 1000 VAC Rms | 1000 VAC Rms | 1000 VAC Rms |
| Remarks | Approved MIL-R-5757B | .... | .... | .... | .... | .... | .... | .... |

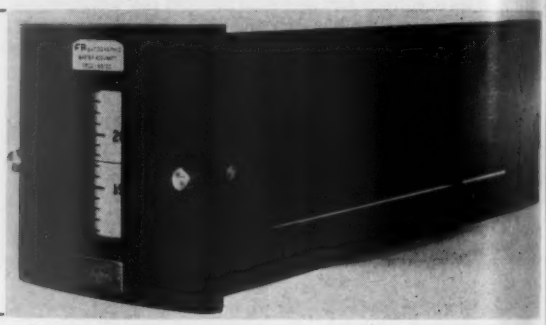
# Instrumentation and Data Reduction Equipment for Use in Guided Missiles and Guided Missile Testing



### ◀Turbine Meters

The F&P Turbine Flow Meter is a lightweight, compact true volumetric flow meter the measurements of which can be converted to mass flow. The fluid-driven rotor rotates at a speed directly proportional to the velocity, and magnetic blades produce as many pulses per revolution as there are blades. Pulse output is fed to counters, convertors or indicators. Digital readout can also be accomplished. Accuracy of the primary element is within $^1/_2$ of 1% of rate in the linear region—extending up to 20-1 for specific fluid conditions. The output is 600 cps full flow. Sizes are available in $^1/_2$ in. through 2 in. for flows from 9 to 210 gpm.





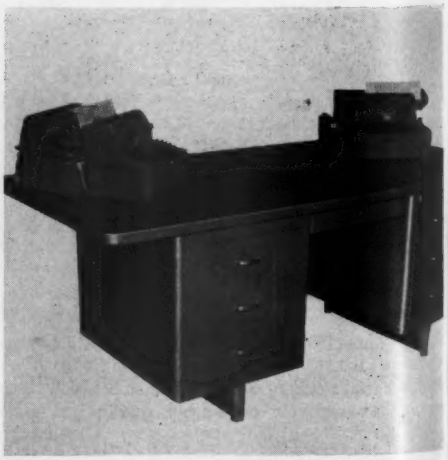
### ▲Variable Area Meters

The F&P Flowrator is a variable area type meter whose fundamental parts are a flow sensor or float capable of free vertical motion installed inside a tube of variable cross-section dependent upon vertical height. In operation, the float seeks an annular area between itself and the tube such that the net weight of the float is exactly balanced by its constant pressure drop and viscous drag forces.

Metering tubes for high pressure applications are made of a variety of metals. The floats are constructed of corrosion resistant metals and plastics. Floats in glass tubes may be read directly, while floats in the metal tube meters are equipped with electronic transmission extensions operating a dial indicator or 72 in. tape minature indicator in an inductance bridge circuit. This system offers the advantage of remote readout. The instruments are normally supplied with accuracies of $^1/_2$% rate. Sizes are available from $^1/_2$ in. to 12 in. with flows at 5 cc/min to 800 gpm.

### Automatic Logger

The F&P Automatic Logger is capable of accepting any number of electrical output signals from thermocouples, transducers, strain gages, etc., and converting this information sequentially into digital form for presentation on typewriters, punched paper tape, magnetic tape, tabulating cards, or any combination of readout devices. Gold-plated contacts on stepping switches, guaranteed for 250,000,000 operations, are used to select each variable in sequence. Voltage-digital converters are used to convert the electrical analog data to any digital presentation specified. Nonlinear signals are linearized and digitized to be direct reading in individually adjustable ranges. All output data are direct reading without the use of graphs or tables.



### Multiple Pressure Readout System

The F&P Multiple Pressure Readout System utilizes a single high-accuracy Press-I-Cell digital pressure measuring device to simultaneously sample and record 200 or more pressures with an accuracy of 1 part in 2000. It is designed for automatic digital data reduction of pneumatic variables in wind tunnels and other test facilities. The system converts samples of all pressure magnitudes to digital information suitable for recording in the form of a typewritten record, punched paper tape, tabulating cards, magnetic tape, or any combination thereof. The system is housed in completely enclosed Parameter Input Cabinet and a Data Handling Cabinet interconnected by electrical lines carrying nonamplitude sensitive signals.

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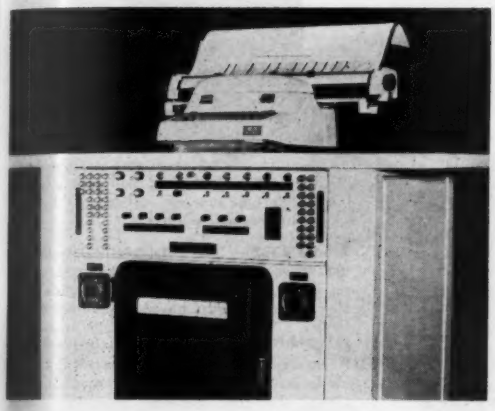
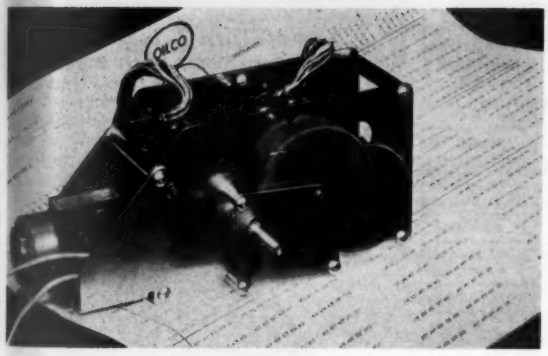


### ◀Qualification Logger & Instrumentation System

The F&P Qualification Logger & Instrumentation System provides a Data Reduction System which automatically records all required data (flow, pressure, temperature, speed, etc.) on a typewriter at predetermined adjustable time intervals. One operator can operate the qualification run and record the data. Timed to the nearest minute, each block of data automatically recorded is presented on one horizontal line on the log sheet. All variables outside of a predetermined limit appear in red on the log sheet and cause an audible alarm to be sounded. All logged data are presented in direct reading units requiring no charts or graphs to determine true reading.

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### ◀Digi-Coder Analog Digital Converter

The F&P Type C-2 Digi-Coder converts input shaft position into discrete electrical contact positions. This is accomplished by mechanical means without the use of brushes, intermittent transfer gears, relays or transfer switches. The output of the Digi-Coder may be furnished in any standard code such as decimal, binary, binary-decimal, teletype, Flexowriter, or in any special code, without the use of external relay or electronic circuitry. Output contacts are rated at $^1/_4$ amp, 40 v d-c. Input torque required is 0.1 inch-ounce.

• • •

### Voltage Digitizer

The F&P Type P Digi-Coder is an automatic self-balancing potentiometer with an integral shaft position digitizer. It is used to convert the output from thermocouples, strain gages, tachometers, etc., into digital form suitable for telemetering to typewriters, tape punches, card punches, and magnetic memories. The Type P, available for both linear and nonlinear inputs, can be supplied with automatic range changing as well as alarm set-points. Accuracy of the Type P is ± 0.15% of full scale with a range of 0–1 mv or greater.

**Write for additional literature and information on any of the above instruments.**

## FISCHER & PORTER

*County Line Road, Hatboro, Pa.*

**Data reduction and automatic systems**
**Centralized control stations**
**Chlorination equipment**
**Industrial glass products**

**Measuring, recording, and controlling instruments**

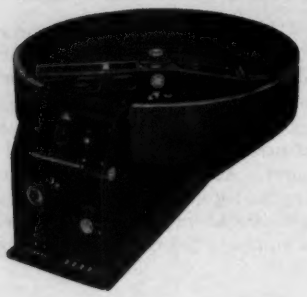
# GENISCO INSTRUMENTS AND TEST EQUIPMENT

## TEST EQUIPMENT

### *G-Accelerators*

Genisco G-Accelerators provide a quick, accurate means of subjecting electronic or mechanical components and assemblies to G-forces similar to those encountered in actual operation.

All models were designed to provide extremely simple operation, necessary accuracy, and to perform for long periods with only routine maintenance. They are suitable for both precise laboratory testing and large-quantity, production-line test programs. Modifications in the basic machines or accessories to meet particular requirements will be given prompt attention by Genisco engineers. Write, outlining your specific needs.



**Model B78**—Used primarily for testing relays, switches, tubes, etc., and for calibrating and evaluating accelerometers.

**Model C159**—The 18″ cubic capacity of this larger machine permits testing of system packages or sub-assembly components of missiles or aircraft.

SPECIFICATIONS FOR GENISCO G-ACCELERATORS

| | Model B78 | Model C159 | Model D184 | Model E185 |
|---|---|---|---|---|
| G-Range | 1 to 120 G's | 1 to 75 G's | 1 to 800 G's | 1 to 60 G's |
| RPM Range | 40 to 420 r.p.m. | 30 to 280 r.p.m. | 60 to 1650 r.p.m. | 25 to 180 r.p.m. |
| Radius of Gyration | 19″ to 24″ | 24″ to 44″ | 1″ to 12″ | 6′ maximum |
| Weight capacity | 25# | 100# each end of boom | 6—1# objects<br>2—10# objects | 300# each end of boom |
| Centrifugal capacity | 1200 G-pounds | 2000 G-pounds | 800 G-pounds | 18,000 G-pounds |
| Accuracies: Performance; Basic Machine | | | | |
| Wow | 0.5% of set speed above 10 r.p.m. | 0.5% of set speed above 10 r.p.m. | 0.2% of set speed | 0.2% of set speed |
| Drift | 0.1% of set speed above 10 r.p.m. | 0.1% of set speed above 10 r.p.m. | 0.5% of set speed | 0.5% of set speed |
| Accuracies: Rate measuring devices | | | | |
| 1. Tachometer | Within 1% above 30 r.p.m. | Within 1% above 30 r.p.m. | Within 2% above 200 r.p.m. | Within 1% above 30 r.p.m. |
| 2. Timer & Counter | Within 1/10 revolution and 1/10 sec | Within 1/10 revolution and 1/10 sec | Not used | Not used |
| 3. Strobe | * Same as D & E | * Same as D & E | Within 0.1% or within accuracy of line frequency | |
| Max. Test Object Size | 8″ × 8″ × 8″ | 24″ × 24″ × 18″ | 6″ × 6″ × 6″ | 30″ × 30″ × 30″ |
| Vibration Isolation | 0.03G up to 500 cps | 0.03G up to 500 cps | 0.03G up to 500 cps | 0.01G up to 500 cps |
| Motor | 1 hp, 220/440V 60-cycle, 3-phase | 1 hp, 220/440V 60-cycle, 3-phase | 1 hp, 220/440V 60-cycle, 3-phase | 7½hp, 220/440V 60-cycle 3-phase |
| Dimensions: Length | 65″ | 105″ | 42″ | Requires compartment 16′ dia. × 7′ high. A recess in the floor 5′ dia. × 2′6″ deep may also be required. |
| Width | 56″ | 96″ | 31½″ | |
| Height | 32″ | 50″ | 67½″ | |
| Shipping Weight | 850# | 2760# | 900# | 6000# |
| Active radius of boom | 19″ to 24″ | 24″ to 44″ | 1″ to 12″ | 42″ to 72″ |

* Optional equipment.

**Model D184**—A high-speed machine for testing accelerometers and other small instruments under high G-forces.

**Model E185**—(Not illustrated.) Accommodates two complete mechanical or electronic packages weighing up to 300 pounds each. Has automatic dynamic balancing system.

***Accessories add to testing convenience***

Accessories for Genisco G-Accelerators include an optical system, air system, additional slip ring systems, mounting stand, strobe system, access doorway and deep tube to accommodate tall test objects.

### *Rate-of-Turn Tables*

**Rate-of-Turn Table, Model C181**—An extremely precise machine for calibrating and evaluating rate gyroscopes, or for low G-force testing and calibrating purposes. It is rugged, simple to operate and built to operate continuously for long periods with only minimum maintenance.

**Genisco Rate-of-Turn Table, Model C181, with Sub-Range Adapter mounted on main turntable.**

### *Specifications:*

*Range:* Infinitely variable from 0.01° per second to 1200° per second

*Turntable Capacity:* 100 pounds

*Electrical noise levels:* Leads are individually shielded and of instrumentation quality. Noise levels in standard rings are approximately −60 db or better.

*Constancy of Angular Velocity:* Within 0.1%, including errors due to wow and drift, at any rate setting.

*Vibration Acceleration:* Not to exceed ±0.015G at frequencies up to 500 cps.

*Accuracy of Rate Settings:*

*By use of drum scale:* Within 1.0% of actual rate.

*By use of tuning fork strobe:* Within .01%.

**Accessories** for the Rate-of-Turn Table, Model C181, include a Precision Strobe System, Sub-range Adapter, and mounting stands.

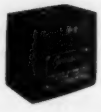
## INSTRUMENTS

Genisco's primary specialization in instrument manufacturing is potentiometer-type accelerometers and pressure transmitters for missile and aircraft applications. Three instruments are now in use on missiles in large-scale production.

The success of these instruments is due largely to the high degree of skill in potentiometer design and manufacture. Unusually clean windings; double-contact, precious metal brushes; and precisely-set brush pressures result in extremely low noise levels.

***Accelerometers*— *These instruments now available in large quantities***

**Accelerometer, Model GMO**—A small, rugged instrument with relatively high natural frequency.



**Accelerometer, Model GLH**—A rugged instrument, thousands produced. Excellent dynamic characteristics over MIL temperature range.

**Accelerometer, Model GOH**—Heated oil damping. A rugged instrument, useful in severe vibrational environments.

**Accelerometer, Model GLO**—Low range unit, primarily. Dynamic characteristics of the Model GLH. Caging available; dual potentiometer output.

**Accelerometer, Model GMH**—Small, heated oil damping. High natural frequency. Excellent performance in severe vibrational environment.

### *Pressure Transducer*

**Model GPT**—Basically an absolute pressure instrument with potentiometer pickoff; can be made for gauge or differential purposes.

**Specifications**

*Ranges:* 0–15 to 0–80 psia.

*Current rating:* 7.0 milliamps for standard potentiometers.

*Resolution:* 0.34% of full scale for standard potentiometers.

*Linearity:* 1.0% of full scale.

*Hysteresis:* Full scale hysteresis is 0.5% maximum.

*Static Friction:* Maximum of 0.5% of full scale.

*Over Pressure:* 50% of rated pressure. Temperature operating range from −20° to +90°C. Output voltage ratio change is 2.0% maximum at temperature extremes.

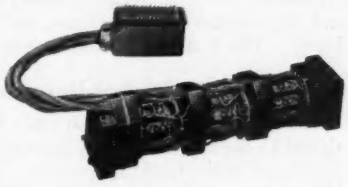
*Acceleration:* Withstands 40 G's, steady-state acceleration without damage. Output voltage ratio change is 3.0% maximum at 20-G acceleration.

*Shock:* No damage from 40-G shock on any axis.

*Vibration:* Not damaged by 10G vibration from 10 to 500 cps. Output modulation is 2.0% maximum at vibration of 5-G from 10 to 55 cps.

*Size:* 2″ dia. × 2½″ long

*Weight:* 11 oz.



### *Analog Digital Converter*

The Genisco Analog Digital Converter (ADC) converts variable mechanical positions into unambiguous electrical contact settings of decimal form.

Each standard decade has ten possible positions. A stack of three decades covers a number range from 000 to 999; a stack of four, 0000 to 9999, etc.

**Specifications**

*Reliability and long life:*
400 × $10^6$ number changes without servicing

96 × $10^3$ number changes per minute possible with special adaptor

*No additional relays required:*
1 amp DC contact rating. Readout taken at standstill.

*Accuracy:* better than one least increment.

*Low torque required:* A three decade unit has a friction breakout torque of 0.5 oz.-in. maximum. Additional decades contribute little additional friction.

GENERAL SPECIFICATIONS FOR GENISCO ACCELEROMETERS*

| | | GLH | GOH | GLO | GMO | GMH |
|---|---|---|---|---|---|---|
| RANGE | | ±2G to ±30G | ±1G to ±3G | ±½G to ±3G | ±1G to ±30G | ±1G to ±30G |
| NATURAL FREQUENCIES | | 6 cps to 23 cps | 7 cps to 12 cps | 6 cps to 10 cps | 10 cps to 45 cps | 10 cps to 57 cps |
| LINEARITY | | Within 1% of full scale | Within 1% of full scale | Within 1% of full scale | Within 1% of full scale | Within 1% of full scale |
| DAMPING | | .3 to .7 critical | 0.4 to 1.0 critical | 0.5 to 0.8 critical | 0.3 to 1.0 critical | 0.3 to 1.0 critical |
| HYSTERESIS (including brush friction) | | 0.05G | 0.05G | 0.03G | 0.07G | 0.07G |
| OPERATIONAL LIFE, MINIMUM | | 3 million cycles | 3 million cycles | 3 million cycles | 1 million cycles | 1 million cycles |
| POTENTIOMETER RESISTANCE | | 1,000 to 10,000 ohms | 5,000 to 14,000 ohms | 5,000 to 20,000 ohms | 2,000 to 15,000 ohms | 2,000 to 15,000 ohms |
| ACCELERATION ENVIRONMENT** | VIBRATION | MIL E5272A Proc. I | MIL E5272A Proc. I | MIL E5272A Proc. I | MIL E5272A Proc. I | MIL E5272A Proc. I |
| | STEADY-STATE | 15G on all axes | 15G on all axes | 10G on all axes | 15G on all axes | 15G on all axes |
| | SHOCK | 30G on all axes | 30G on all axes | 15G on all axes | 30G on all axes | 30G on all axes |
| OPERATIONAL TEMP. RANGE | | −65° F. to +200° F. | −50° F. to +180° F. | −65° F. to +180° F. | −10° F. to +180° F. | −60° F. to +180° F. |
| OVERALL SIZE | | 3⅛″ × 3¼″ × 2¼″ | 3¼″ × 3¼″ × 3¾″ | 3¼″ D. × 3/16″ | 1⅛″ × 1⅛″ × 3⅛″ | 1 31/32″ × 2″ × 4¾″ |
| RESOLUTION | | 0.30% | 0.34% | 0.34% | 0.34% | 0.34% |
| WEIGHT | | 2 to 2¼ lbs. | 2 lbs. 6 oz. | 2½ lbs. | ½ lbs. | ¾ lbs. |
| BRUSH CONTACT RESISTANCE | | Equivalent contact resistance less than 100 ohms at 0.1 ma brush current | | | | |

* Exact specifications for particular instrument applications will be submitted upon request.
** Higher ranges better in regard to environmental conditions.

*Reliability first*

**2233 Federal Avenue, Los Angeles 64, California**

Genisco INCORPORATED

# Giannini Datex Digital Data Recording Systems

GIANNINI DATEX SYSTEMS have been produced for Radar Digitizing, Wind Tunnel Instrumentation, Gas Dynamics Research, Weight Display and Recording, Rocket and Jet Engine Test Facilities, and Automatic Computer Input. The Radar Digitizing Equipment is described herein.

### Model 14321 Digital Data Recording System

Giannini Datex Model 14321 Data Recording System is designed to digitize and record information produced by radar equipment while tracking aircraft. This system records the information on a punched tape, either for direct input to a computer or for transmission over standard Teletype circuits. Other types of outputs, such as punched card or printed tabulation, can be supplied to meet specific applications. The data are obtained in analog form from the azimuth, elevation, and range shafts of the tracking radars, and are converted by the Giannini system into digital form and instantaneously recorded on standard Teletype perforated tape.

The tape is punched in a code, which is binary coded decimal and in word lengths of eleven decimal digits. Each decimal digit is coded in terms of four holes punched in a row across the tape. Each group of eleven digits is preceded by a hole in the fifth column which is termed "Beginning-of-Word" code.

The shaft positions in the radar are measured with the following precision:

1 Range—one yard out of 1,000,000 yards maximum.
2 Elevation—0.005° out of 100°.
3 Azimuth—0.005° out of 360°.
4 Tracking Rates—
Elevation and azimuth: 30°/ sec max.
Range: 8000 yds/sec max.

This results in six decimal digits of range and five decimal digits each of elevation and azimuth.

The equipment is designed so that two complete readings of elevation, azimuth, range, and time can be made each second. In order to insure reliability, two tape punches are used. One punch, Channel "A," prepares a tape containing all data taken at the beginning of each second; the second punch, Channel "B," prepares a tape containing all data taken at the midpoint of each second.

The circuitry associated with these tape punches has been made as independent as possible so that a failure in any one channel will not influence the operation of the second, thus increasing the reliability of the equipment through redundancy. Since it is usually necessary that the data be synchronized with time, provision is made in the equipment to accept and record time in binary coded form. (Provision can also be made to record time in binary coded decimal form if required.)

The complete Giannini Model 14321 Data Recording System is shown in Fig. 1. The tape punches are shown on the table, while the control and data processing equipment are shown within the cabinet. The commutators can be seen in the lower foreground. The equipment is designed so that all tubes are located at the front of the cabinet and all wiring and cables are located in the rear.

The radar shaft positions are coded by means of commutators. For example, the large (2000 count) commutator is mounted on the 2000-yd range shaft in the range unit of the radar. Each 180° sector of this commutator is divided into 1000 segments, and each segment is defined by a unique combination of contact closures. These contacts are formed by twelve brushes riding on the photo-etched pattern of the commutator. Each group of four brushes generates a code defining one decimal digit. This code has been designed so that any two adjacent numbers differ in only one contact closure. At any position of the commutator, only one brush is passing from a conducting to a nonconducting segment. This avoids ambiguities and errors that inevitably occur if simultaneous contact changes are required.

Any error existing because of backlash in the radar gearing is avoided by utilizing Double Disc Commutators. The small commutators shown produce a coded output defining the number of revolutions of the 2000-count commutators, and generate the larger significant digits.

One large commutator and two small commutators are mounted on the range unit. The large commutator on the 2000-yd shaft counts to 1000 twice. The small commutator on the 50,000-yd shaft counts to ten five times, and a third commutator mounted on the 1,000,000-yd shaft counts to 100 once. Thus three decimal digits are obtained from the 2000-yd shaft, one decimal digit from the 50,000-yd shaft, and two decimal digits from the 1,000,000-yd shaft.

Similarly, commutators are mounted in the radar antenna pedestal to measure elevation and azimuth. All commutators have been designed to be interchangeable with synchro units which they supersede.

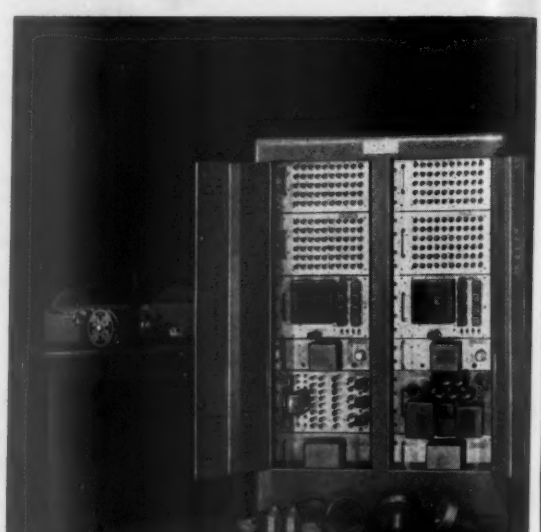


**Fig. 1 Model 14321 Digital Data Recording System**

The storage and control circuits are contained in the cabinet, as shown in Fig. 1, and can be divided into three groups. The first group is Channel "A," which punches data at the beginning of each second. The second group is Channel "B," which punches data at the middle of each second. The remaining group is common to the complete system.

The circuits of Channels "A" and "B" are identical and consist of storage, control, and power supply. The storage circuits consist of one thyratron for each brush of each commutator. When the commutators are pulsed, the thyratrons are fired if the associated brush is making contact with the commutator conducting pattern at that instant. The control circuits include a stepping switch which connects the thyratrons to the teletype punch in groups of four. The thyratrons then operate the punch magnets directly, and when all data are recorded, the thyratrons are "cleared" in preparation for the next readout pulse.

(*Continued on page 45*)

# Specialized Experience in Handling and Control of Fuels and Corrosive Liquids

**JOHN T. MARSHALL, Chief Engineer**
**Hamilton Division, Bendix Aviation Corporation**

THE increasing number of fluids being handled in all branches of science and industry have created new problems for the manufacturers of hydraulic and fuel pumping equipment and controls. The lubricating, sealing, rust proofing, oxidation resisting, and emulsifying properties of fluids being handled are all important features to be considered. The engineering personnel of the Hamilton Division of Bendix Aviation Corporation have specialized in fuel handling components both pumps and controls, for high speed aircraft and military type engines.

***Build Pump Adaptable to Many Pumping Requirements***

It is with this background of engineering and production experience that the Multi-Media Pump was designed and built to handle a large variety of corrosive and noncorrosive liquids such as are being used or proposed for use in high speed jet and rocket propulsion. At the time of manufacture the materials selected for the individual components may be varied to provide the maximum compatibility with the fluid to be handled.

The pump is of the axial piston type having six cylinders. The stroke of the pistons and/or the displacement of the pump is determined by the angular relationship of the rotating wobble plate. By varying this angle (at the time of manufacture) a wide range of pump capacities may be obtained. The method of valving provides smooth, quiet operation with a minimum of output flow pulsation.

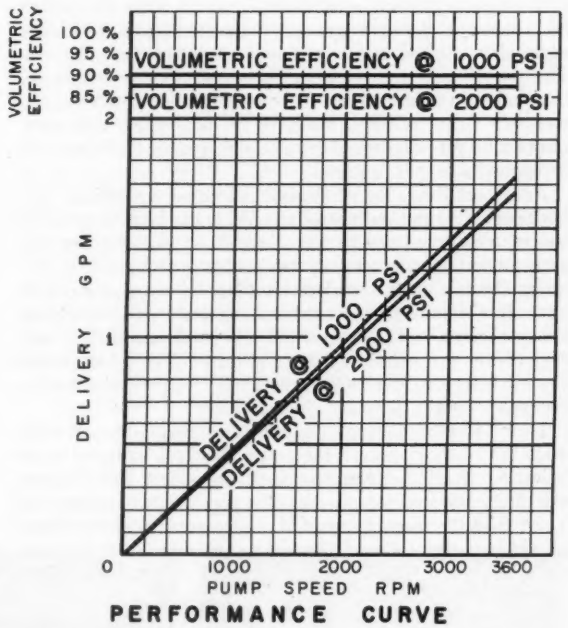
The Multi-Media Pump has been designed for ease of installation and service without special tools or technique. Mounting pads, couplings, and ports conform to aircraft specifications. The mounting position and direction of rotation are optional without internal alteration or change in external piping.

High volume efficiency and good high altitude operation are distinctive features brought about by minimum plunger to bushing clearance and positive valve action.

The Bendix Multi-Media Pump can handle a wide range of corrosive and noncorrosive liquids including those having abnormally low viscosities. The selection of material combinations for plungers and plunger housings together with precise clearance fits and high polish makes it possible to handle a wide variety of liquids and gives the plungers a long life when operating with poor lubricating fluids.

The pumping action is by reciprocating plungers in a fixed housing. The plungers are actuated by a rotating wobble plate. To maintain a minimum pump size the wobbler is designed to act as the bearing race for each of the two thrust bearings. For lubrication the drive section rotates in a bath of oil having a specification which makes it compatible with the fluid being pumped. If a severe corrosive agent is being handled, polymers of trifluorovinyl chloride, which has great resistance to oxidation, may be used as a lubricant. The fluid being pumped is kept from entering the lubricated drive section by the very close plunger to bore clearances and by "O" rings on each plunger. Teflon rings are used when the corrosive nature of the liquid so warrants. The pump is so designed that the seals work against the relatively low inlet pressures instead of the higher discharge pressure.

Inlet flow to the pump is from the center of the pump housing to an annulus which surrounds each plunger. The fluid then passes up through the plunger to the underside of the inlet check valve located in the head of the plunger. Inertia forces caused by the weight of the valve in the reciprocating plunger are the activating forces which open and close this valve. Thus, during the suction portion of the stroke, the inlet valve will be held open to permit flow into the plunger chamber, and on the outward or pressure stroke the inertia forces acting on the valve, together with the pressure built up in the plunger chamber, tend to hold it closed. As the pressure inside the plunger chamber builds up to and exceeds the output pressure, the discharge valve will open. The action of this valve being a direct function of chamber pressure and rate of flow of fluid from the chamber, line surges, due to rapid opening and closing of mechanically operated valves are minimized.



**PERFORMANCE CURVE**

Materials being successfully handled to date include: fresh or sea water, Hydro-Carbon fuels and lubricants, Ethylene Oxide, Titanium Tetrachloride, 90 per cent Hydrogen oxide, and other similar fluids. Our engineers will be glad to discuss with you how this pump and related controls may be adapted to your pumping problems.

Bendix AVIATION CORPORATION, HAMILTON DIVISION, HAMILTON, OHIO

# Grand Central Rocket Co.

FRANK MARION

**Director of Technical Service, Grand Central Rocket Co.**

BECAUSE of the security aspects involved in describing specific "equipment" of a rocket developing and manufacturing organization, this article is presented to make the reader *generally* aware of the products, facilities, and services available at Grand Central Rocket Co.

Grand Central Rocket Co. is comprised of a team of engineering, scientific, and production personnel managed and directed by recognized leaders in the solid propellant rocket industry. The sole purpose of this team is to engage in applied research, development, and production of solid propellant power plants for all types of rocket applications. A major portion of effort is assigned to the design and development of high performance solid propellant rocket motors for missile propulsion systems.

Several of the earliest proponents of solid propellant power plants for large guided missiles are now key personnel of Grand Central Rocket Co.—men of vision who originally advocated, and actively participated in, the development of a series of large composite solid propellant missile power plants. With farsightedness, dedication, and determination, these men and their colleagues have pioneered the large missile concept in the composite solid propellant field. Their success can be measured by the ever-increasing numbers of missiles using such power plants.

In order to develop missile power plants with still higher performance and even lower cost, Grand Central is constantly engaged in applied research of new propellant formulations. The aim of such research is to discover properties which can be applied to achieve increased versatility and usefulness of rockets. Grand Central's wealth of experience with composite solid propellants assures a sound fundamental approach to applied research problems.

In a short time, Grand Central developed an entirely new high performance solid propellant which has been demonstrated in rocket motors to have important performance and cost advantages for missile propulsion. On another program, Grand Central developed a unique, low-cost propellant with low temperature, nontoxic, noncorrosive, smokeless exhaust gases. Still another recent development is a new high energy propellant. These and many other achievements are evidence of Grand Central's ability to pace the field as composite solid propellant specialists.

Grand Central does not manufacture propellant raw materials but, rather, surveys the entire chemical industry before selecting the ingredients for new propellant formulations. All materials are purchased on a competitive market and must meet the most stringent of quality control specifications. A wide variety of Grand Central propellants are now available. However, Grand Central produces rocket power plants of *any* formulations selected by the customer.

Because the solid propellant is the heart of solid propellant power plants, Grand Central has built its facilities primarily for development and production of propellants. However, in order to obtain integrated power plant efficiency, the metal components for the rocket power plant are usually under the control of Grand Central's design specialists. Actual fabrication of metal components is subcontracted to facilities specializing in the techniques required for the particular job. Subcontracts are awarded on a competitive basis to qualified fabricators and the components are subject to Grand Central inspection and quality control tests. Sometimes the customer furnishes his own metal components, in which case Grand Central confines its contribution to propellant loading and quality testing of the end product. *In any event, the policy is to serve and not to compete with the customer.*

To serve its many customers better, Grand Central has built and privately owns a new and modern facility designed specifically for propellant production and testing. The first phase of construction, completed in July 1954, consisted of 15 buildings fabricated, for the most part, of fireproof reinforced concrete. The production capacity with the basic equipment installed in this first unit of construction was approximately 400,000 pounds of composite propellant per month. More buildings have been added during the past year and the most recent expansion included facilities for production of large missile motors. The production capacity can be expanded to several million pounds per month on the existing property site without exceeding quantity-distance regulations. Grand Central's staff includes personnel experienced in the design and construction of such large production facilities, and rapid expansion can be achieved as requirements grow.

Static test cells of heavily reinforced concrete, buried partly underground for additional safety, have been constructed to test large thrust units. Adjacent to the test cells, for rocket motor conditioning, refrigerators and ovens have been provided to supply temperature environments from −100 F to +200 F. Isolated areas are available where special setups and tests of very high impulse units can be made without interfering with routine rocket motor development tests. A special facility of this type is currently in the design stage.

Experience, ability, and team work have been demonstrated in the development and production programs conducted by Grand Central. Many of these programs have been completed within a period of six months after acceptance of the contract. Customers have learned that they can depend on Grand Central for accurate cost estimates, firm delivery schedules, and delivery of a high quality end product.

As a result of past successful development programs, Grand Central is currently participating in a number of major missile development projects.

Grand Central welcomes all opportunities to bid on projects which are to be awarded on a competitive basis. A balanced group of aerodynamicists, mechanical and chemical engineers, structures engineers, chemists, and physicists makes Grand Central's team capable of designing rocket motors from the broad systems analysis point of view. Consultations and prompt, carefully considered proposals—including design studies, calculations, and working drawings—are part of Grand Central's technical services.

**Air View of Grand Central Rocket Co. Facilities**

# Hydraulic Helium Booster Compressor Produces Large Quantities of Contamination-Free High Pressure Gas

**R. L. HAYMAN**

**President, Haskel Engineering and Supply Co., Glendale, Calif.**

WITH the step-up in the guided missile program, there has developed an increasing need for larger quantities of high pressure gas free from oil or other contamination for servicing missiles and for tests related to their development.

The gas usually used is helium or nitrogen and is obtained originally in commercial cylinders pressurized at approximately 2000 psi.

Staff engineers of Haskel Engineering and Supply Company, Glendale, Calif., have come up with the answer to this problem in the form of a multiple stage hydraulic booster compressor for helium which incorporates simplicity of design and operation. The end result is gas produced at desired pressures in desired quantities and free from contamination.

Prior to development of the Haskel booster compressor, two methods of compressing have been used in the program. One is the accumulator and the other is the single stage booster.

In the accumulator method, oil placed under pressure and separated from the gas by a diaphragm is used to boost the gas pressure.

The other method used is the single stage, double acting boost cylinder driven by either air or hydraulic power. It is relatively efficient and simple in operation. Like the accumulator, however, it must work under limited compression ratios in boosting gas pressure with the maximum ratio at about 4 : 1.

In approaching the problem our engineers determined that a method utilizing several stages of compression within the pump would prove to be an effective solution. A conventional type multiple stage compressor could have been used. This, however, would have presented the disadvantage of wasting energy in that high pressure gas in the cylinders would have required reduction to a low fixed inlet pressure at the compressor. This type of compressor also adds considerable foreign matter to the gas that must later be removed.

After further designing and testing, the Haskel staff found they could adapt a double hydraulic booster to as many stages as needed. A method was devised of constructing a multiple stage compressor which is self-regulating for maximum output at any inlet pressure between minimum and maximum available. The over-all performance of such a booster when operating over a wide range of inlet pressures is a considerable improvement over any of the methods that have been discussed previously.

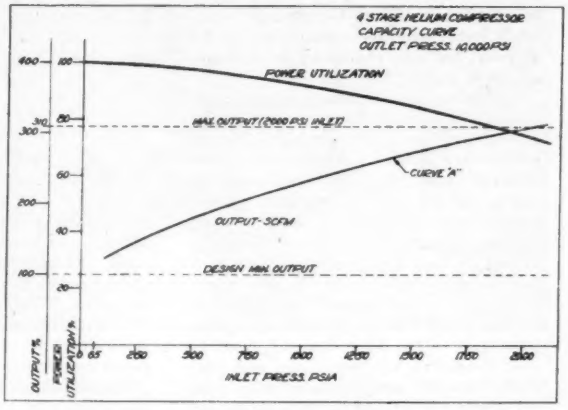



**Fig. 1 Performance curves for typical four-stage booster**

Fig. 1 shows performance curves for a typical four-stage booster in SCFM when compressing gas from 50 psi to 10,000 psi. From curve A it can be seen that the output from the booster rises sharply as inlet pressure becomes greater than 50 psi minimum requirement. When inlet pressure has inincreased to 2000 psi (the pressure available from commercial bottles) the output has increased to 300 per cent of the minimum required output. Also at this point the power utilization is still relatively high despite the high inlet pressure.

The significance of this performance can be appreciated when compared with that of a conventional mechanical multiple stage compressor which works from a fixed inlet pressure. It would take such a compressor, with the same minimum design requirements, approximately twice as long to pump up a receiver to a given pressure from a supply of 2000 psi gas which has to be reduced to 50 psi. Conversely, it would require twice the capacity to do the job in the same time.

The Haskel multiple-stage hydraulic booster compressor retains much of the simplicity and compactness of the single stage booster. In addition, since its piston velocity is extremely low, it is designed for successful operation without lubrication in operations where any contamination of the gas is undesirable.

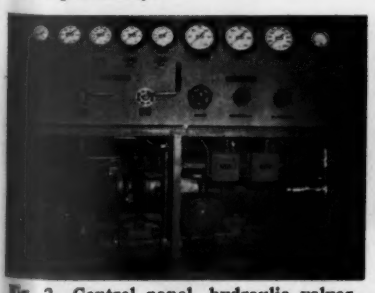


**Fig. 2 Control panel, hydraulic valves, and gas pressure switches of multiple stage hydraulic booster compressor**

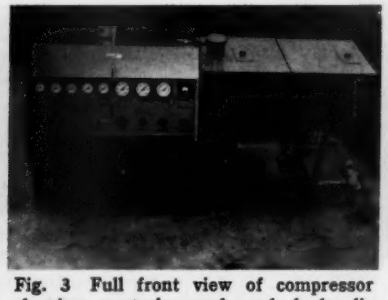


**Fig. 3 Full front view of compressor showing control panel and hydraulic reservoir**

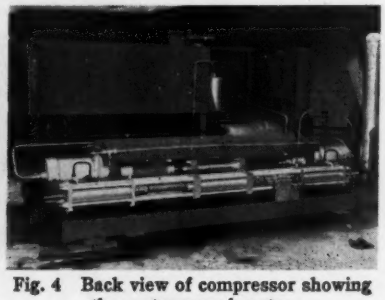


**Fig. 4 Back view of compressor showing three-stage gas booster**

# Power for Guided Missiles

By JOHN H. BLANKENBUEHLER
Design Engineer,
Hobart Brothers Co., Troy, Ohio

Manufacturers of generating equipment supplied to the contractors building guided missiles, as well as the Military Services using them, have learned quite a lot about the characteristics required in that equipment. The missiles themselves are quite a confidential subject and the manufacturer of the Generating Unit rarely learns why the requirements are as they are, but does encounter the requirements in making the sets.

Generating sets for this purpose are provided in the form of direct current 28 volt, alternating current 60 cycle and 400 cycle generators. Each of these three types seems to be used in a different manner as might be expected. Power for guided missile work generally is used to start engines in the missile, to operate actuators in and around the launching ways, and to operate missile guidance and target tracking radar and other radio equipment.

The direct current generating equipment (Photo No. 1) is generally used to start the missile engines, if any, and generally has the same characteristics used for starting a jet engine in a fighter or bomber aircraft. This consists of constant voltage at about 28 to 30 volts from no load to a given output and then a constant current characteristic from that point to short circuit or a modified constant current characteristic. More recent developments have tended to eliminate all control apparatus from sets of this type using generators with inherent characteristics rather than generators equipped with special regulators. This same direct current power may be used to power fuel pumps, invertors and other equipment on the missile or connected with the launching.

The 60 cycle equipment is used for general power to run the hydraulic power systems, radio sets and in some cases to power an electric motor driven direct current set such as mentioned above. These 60 cycle sets have in a few cases, stringent requirements as to wave shape, voltage regulation, transient reactance, etc. Most of the extremely stringent requirements as to generator characteristics are, however, connected with the 400 cycle applications.

Fig. 3 30-kw, 400-cycle engine driven generator used for radio and radar power supply

The 400 cycle generator is most often used for powering radio or radar equipment, and in most cases requires extreme care in design to provide the proper characteristics. These sets must provide power of extremely constant voltage and constant frequency and are generally three-phase but must allow a rather large single-phase load to be applied without upsetting the balance of the three-phase voltages. The voltage regulation is usually plus or minus 1% and the frequency regulation is about the same on engine driven sets but, of course, on motor driven sets using a synchronous motor (Photo No. 2) it can be zero. This constant frequency provided by synchronous sets is required in some cases.

The wave shape of these sets, both 60 and 400 cycles, is generally limited to a harmonic content of 5%, but sometimes to a harmonic content of 2%. The frequency must be constant and have a modulation of less than plus or minus ¼ to ½%. The voltage must be also held constant and have a modulation of less than 1%.

The generators are sometimes required to start rather large motors and for such applications require a low transient reactance of the order of .25 and a high short circuit ratio of the order of 1.5 to 2.0.

Most of these sets, whether AC or DC, are equipped with a number of protective safety devices such as overvoltage relays which trip the unit from the line in an inverse time ratio to the amount of overvoltage. They also have low voltage relays, low frequency relays, high frequency relays, and other devices to indicate variation from frequency without tripping from the line. Engine driven equipment (Photo No. 3) has the usual high water temperature, low oil pressure, etc., protective devices. Of course, most sets have an overload relay but this seems to be the least important of all.

All of these sets are provided with various types of motor power. Those at permanent launching sites are equipped with alternating current motors and where the frequency requirements are close, a synchronous motor is used. This, of course, provides the most ideal frequency characteristics. Engine driven equipment can be provided giving 2% frequency change with load, with conventional type governing equipment and, with electronic governors, can be made to give constant frequency. Much of this equipment is for field service and of course has accessories and attachments making it particularly suitable for this work. Some equipment is arranged for operation at −65° F. while at the same time being suitable for operation at extreme altitude and high temperatures. It is probable that equipment for this purpose presents more new problems to the generating set designer than any other application. These problems are all being met successfully and equipment is now available to give the missile engineer any characteristic he desires.

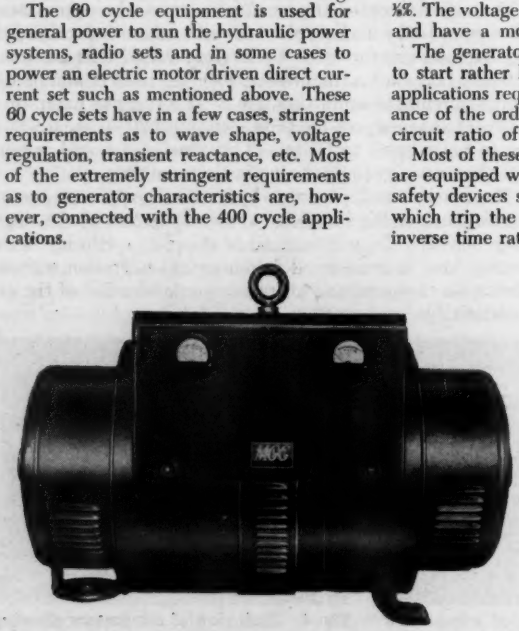


Fig. 1 750-ampere, 28-volt, DC motor generator used on missile launchers

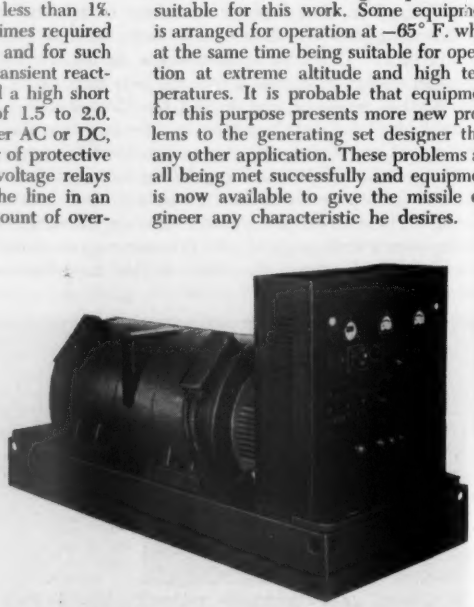


Fig. 2 30-kw, synchronous motor-driven, 400-cycle AC generator used for power supply of various missile components

# Photographic Data Recording and Instrumentation Systems

L. A. ROOT, Chief Administrative Engineer

J. A. MAURER, INC.

ADEQUATE instrumentation is always a necessity to permit proper analysis of any test; when dealing with the flight performance of unmanned vehicles (or manned vehicles, where the crew has a full-time task performing necessary control functions), its importance cannot be overestimated.

Under such circumstances, photographic data-recording techniques often prove the optimum system for obtaining and permanently recording data for subsequent analysis.

As compared to other data storage systems, the photographic process has a great deal in its favor: it is reliable, and it is consistent. A properly designed photographic system cannot be equalled for ruggedness, compactness, low-power consumption, and light weight for a given information capacity. Recent advances in photographic development techniques have made portable developing machines of small size and large output rates a reality, eliminating the one previous serious disadvantage: immediate availability of data.

From its very beginning as an organization, J. A. Maurer, Inc., has specialized in the design and manufacture of precision photgraphic apparatus and in the applications engineering required to solve instrumentation and recording problems, both military and industrial, by photographic methods.

In addition to the high standards of craftmanship that are a heritage from the professional 16-mm motion picture cameras and sound recording equipment designed and produced by the company for many years, a fund of knowledge regarding the problems peculiar to airborne equipment has been augmented in more recent years. These problems of extreme compactness of configuration, dependability, serviceability, light weight, low-power consumption, precise and reproducible performance despite wide variations in temperature, humidity, and pressure and resistance to deterioration by corrosion, dust, or fungus, have been faced and solved, as exemplified best, perhaps, by the thousands of Strike-Attack Cameras of the P-2 and CAX-1 Types currently in use by the U. S. Air Force and U. S. Navy in fighter aircraft.

This background, combining considerable experience in the design of 16-mm motion picture cameras achieving image quality so far in excess of customary 16-mm standards that they are usually mistaken for the results produced by 35-mm equipment, together with the experience gained in meeting many performance and environmental requirements for the U. S. Air Force, U. S. Army Signal Corps, and U. S. Navy Bureau of Aeronautics, coupled with the applications engineering experience derived from the solution of many industrial, medical, and military data recording problems, offers considerable promise in the solution of hitherto unattempted recording problems.

Many categories of photographic recording apparatus fall within the scope of this company's experience; among them, may be named the following:

1 Motion Picture Cameras of extremely precise image registration and high resolving power for both normal and high frame rates.

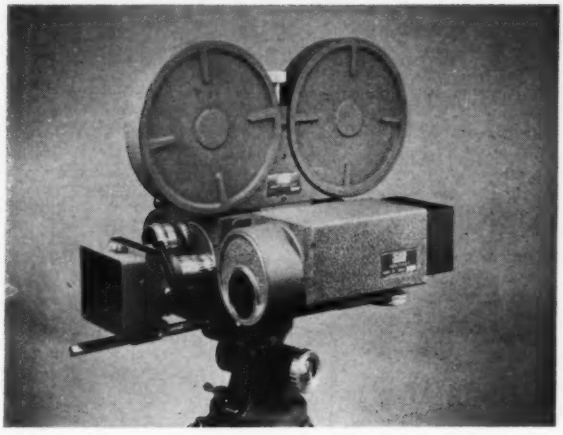
2 Internally and Externally Pulsed Sequence Cameras, for instrument panel recording.

3 Radar and Oscilloscope Recording Cameras.

4 Aerial Reconnaissance Cameras of exceptionally compact dimensions and high performance.

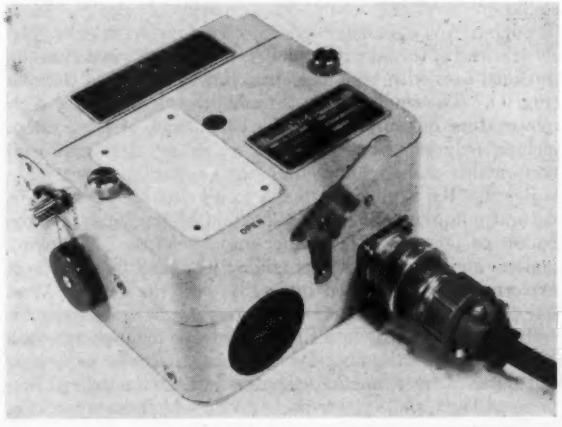
5 Sequence Cameras, for air-to-air or air-to-ground rocket impact recordings.

(*Continued on page 45*)



**The Maurer Model 150 Professional Motion Picture Camera**

This is a precise professional-type tripod mounted 16-mm camera, suitable for all sorts of documentation photography where exceptional image steadiness and sharpness are necessary. Among its features are 140-power thru-the-lens focusing on a clear glass reticle, interchangeable 200, 400, and 1200 ft magazines, 235° variable and dissolving shutter, parallax corrected viewfinder with built-in masking device for lens focal lengths from 15 to 152 mm, and a full range of motors for AC or DC operation, from single-frame animation through high speed rates. It is currently in use by many government agencies and industrial concerns for all types of test documentation photography.



**The Maurer Model N-11 16-mm Reticle Gun Camera, Designed and Manufactured for the U. S. Air Force**

This camera is designed to form part of the Optical Gun Sight system in fighter aircraft, to record aiming point information, and thus serve as a check on pilot proficiency and gunsight accuracy. It represents the almost irreducible minimum in size, weight, and power consumption, yet meets all environmental requirements of the U. S. Air Force for airborne equipment. With dimensions of $4^3/_8$ inches × $3^3/_8$ inches × $2^1/_2$ inches, a weight of 3 lb, 5 oz., and a power consumption of 3.6 amps at 27 volts DC (including internal heaters), it is a good example of how much may be accomplished through photographic data recording when space is limited and power and weight must be minimized.

# Squibs, Squib-Igniters, and Power-Packs

FRANK W. LAHAYE

McCormick Selph Associates, Hollister, Calif.

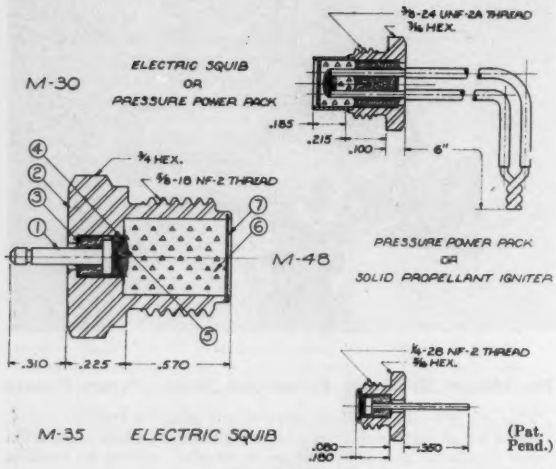



Fig. 1 Typical units

A NEW concept of electric squibs, igniters, and explosive ordnance "power-packs" has emerged because of the need for simplification in electrically initiated explosive systems. The development of a pressure tight squib (electric primer) has reduced the difficulties of conventional squib installation involving complicated wiring of electric leads through complex pressure seals into reaction chambers. The electric lead of the new type squib is hermetically sealed to the threaded case with high dielectric, pressure stressed ceramic (Fig. 1). The squib can be threaded directly into any high temperature pressure chamber. Advantages of this system include reduced costs, increased reliability, and improved performance and environmental storage characteristics.

Because the squib is germane to all explosive systems, a natural outgrowth was the unification of the squib and the igniter or power-pack container into one part. Therefore, igniters and power-packs containing less than five grams of explosive are constructed integrally with the squib. Most units containing more than five grams can be more economically constructed by utilizing a separate main-charge case and a threaded-in squib. Power-packs are similar to igniters but differ in their function—igniters initiate the deflagration of propellants, while power-packs produce high energy gas for use in pressure actuated systems (Fig. 2).

A hermetic and pressure seal is obtained by high temperature fusion of a pressure-stressed ceramic (3) to the steel contact pin (1) and case (2). The ceramic has an insulation resistance in excess of 10,000 megohms. The headed-type contact pin when placed under thermal shock and pressure exerts compressive, instead of shear, stresses on the ceramic. This system has supported 60,000 psi applied in 10 milliseconds. The unheaded contact pins of the M-30 fail at 8000 psi hydrostatic.

To insure reliability, a welded, parallel circuit of nichrome or platinum-iridium bridge wire (4) is used and makes unnecessary the use of two single circuit squibs.

On heating of the bridge wire (4) by application of d.c. current, the heat sensitive priming material (5) initiates the main charge explosives (6). Lead styphnate, diazodinitrophenol, and proprietary zirconium priming mixtures are used. Some are capable of high temperature storage (400°F–24 hr) and initiation at 90,000 foot altitudes.

When used in an igniter, the main charge (6) contains ignition materials whose type and grain size are controlled by parameters of the propellant to be ignited. When used in an explosive "powerpack" the required interior ballistics of the actuator system (Fig. 2) determine the composition, and grain or pellet size of the main charge. Typical igniter materials are black powder, metal-oxidizer combinations, and single or double base propellants, while power-pack materials are gun propellants or black powder.

Aluminum or nitrocellulose closure disks (7) are crimped and sealed with NRC or epoxy compounds. Hermetic ring welding of metal closures is currently being developed. Contact pins which can be attached to crimp or disconnect Stakon or AN connectors are illustrated and are available in 1, 2, or 3 pin styles.

Products manufactured by McCormick Selph include squibs, igniters for liquid and solid propellants, high explosive bolt cartridges, explosive detents, gas generating canisters, and pressure power-packs.

Power-packs like the M-48 and M-47 are used in the following applications: piston pressure (Fig. 2) for bolt and parachute release, cable and bolt cutters, liquid fuel valves, multiple stage missile separation, seat and canopy ejection, and rocket launcher, jato and wing tank jettisoning.

Numerous squib, igniter, and power-pack units have been developed for, and tested by, engineering groups engaged in actual design and production of liquid and solid fuel motors, release mechanisms, gas generators, fracture bolts, and other explosive ordnance devices. The reliability and performance records obtained from these sources together with static testing conducted by McCormick Selph are compiled into Technical Data Sheets on each unit. Information in these regular bulletins includes: minimum and maximum static sensitivity, maximum current for zero probability of ignition, applied current vs. functioning time curves at ambient, −65°F, and +165°F, bomb chamber pressure and time data, and a detailed part description.

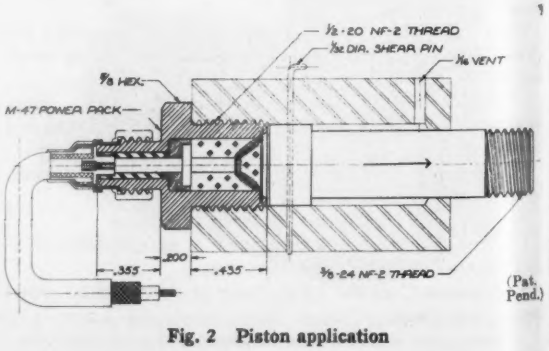



Fig. 2 Piston application

# Tiny, Ultraprecise Bearings Vital to Instrumentation

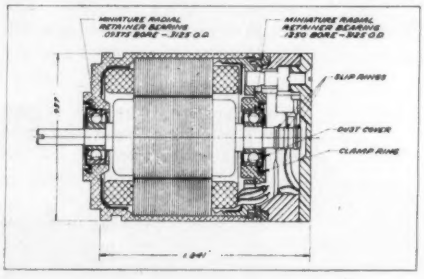
THE extraordinary achievements that are so common today in flight science are being realized largely through the amazing performance of modern control instruments. Yet, even as they become more precise and complex, these electro-mechanical systems—and their thousands of components—must continually be reduced and compressed again and again, in order to perform more functions with less weight and bulk.

Of the many critical mechanical components used in missile instrumentation, none is more important than the simple ball bearing. Miniature Precision Bearings, Inc., Keene, N. H., has pioneered in the research and development of miniature ball bearings for use in precision instruments. The MPB bearings that mount the rotating shafts of countless instruments now providing control data for missile guidance have met and exceeded the most rigid requirements of modern instrumentation.

Manufactured to precision tolerances, in over 500 standard types and sizes and in innumerable special designs, these bearings accurately position and support the rotating shafts of synchros, gyros, potentiometers, gear trains, and similar components for extended periods of life under almost every conceivable condition of operation. Low torque, minimum axial and radial play, and negligible backlash under varying loads are characteristic performance qualities of every precision MPB ball bearing.

### *Synchros*

Synchros transmit and receive positional data between distant points, and are commonly used to monitor missile fins. Both electrical and position accuracy of miniature synchros depend largely on the rotation characteristics of the rotor shaft. The types and mounting of the bearings supporting the shaft have a critical effect on the over-all performance of a synchro and other similar electro-mechanical devices, such as servo motors and resolvers.


MINIATURE RADIAL RETAINER BEARING .0375 BORE - .125 O.D.
MINIATURE RADIAL RETAINER BEARING .250 BORE - .625 O.D.
SLIP RINGS
DUST COVER
CLAMP RING

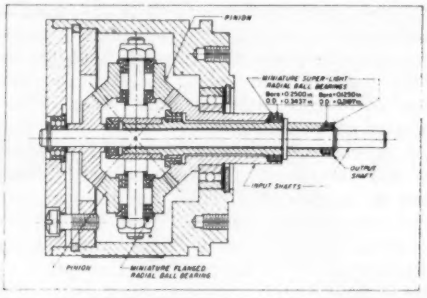
One of the smallest, most precise synchro receivers available—with a torque gradient of 2300 mg-mm/deg and an electrical accuracy spread of 30 minutes maximum—is shown in Fig. 1. This degree of precision has been achieved by maintaining frictional torque and shaft play below extreme minimal limits.

Operating specifications were exceeded in this synchro primarily by mounting the rotor shaft on miniature radial retainer ball bearings whose frictional torque and radial play were inherently lower than required. Both bearings have stainless steel snap-type retainers with coined ball pockets to provide minimum torque. In addition, lubrication of the bearings before assembly is carefully controlled to prevent possibility of ball drag in races due to excess lubricant.

Because the required axial play of 0.002–0.004 in. is critical, standard MPB bearings are tested and selected for axial play less than 0.001 in. at specified temperature extremes.

### *Gear Shafts*

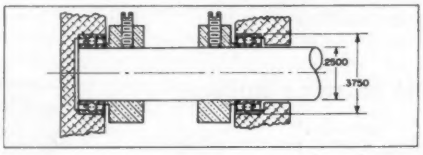
Differential gear units, used as computing elements in missile navigational systems, also must operate with almost incredible accuracy. The concentric input shafts of a unique new differential require the support of specially designed, super-thin radial ball bearings. Extending from the same end of a servo-mounted case instead of from opposite ends of the spider as in conventional differentials, the two input shafts, $^1/_8$ in. and $^3/_8$ in. in diameter, pass through and enclose




the $^1/_4$-in. diameter output shaft. As can be seen in Fig 2, the outer concentric shafts are supported on ball bearings mounted on the next inner shaft. Because the radii of these concentric shafts differ by only $^1/_{16}$ in., specially designed ball bearings are necessary to support them and maintain shaft end-play at less than 0.001 in. Made to ABEC 5 tolerances, each of these tiny ball bearings has a radial thickness (from bore to outer diameter) of only 0.0469 in.

### *Potentiometers*

The degree of electrical accuracy of single-turn and multi-turn precision miniature potentiometers, widely used in control servomechanisms and analog computers, depends a great deal on geometric accuracy. The accuracy of the potentiometer shaft in Fig. 3 is assured by precision construction and operation of the bearings, while their small wall thicknesses provide maximum saving of weight and space.




A related mechanical consideration in potentiometer design is the magnitude of frictional torque that must be overcome to rotate the shaft and wiper assembly. To minimize this torque the shaft shown is mounted on shielded radial-retainer miniature ball bearings. The coined ball pockets of the retainers maintain the frictional torque of the specially lubricated bearings at a minimum throughout an extremely wide temperature range. Bearing shields protect the interior of the potentiometer from contamination from outside sources.

MPB engineers are prepared to assist you in the solution of problems arising from specific applications. For new 24-page General Catalog, technical data or assistance, write Engineering Department,

**MINIATURE PRECISION BEARINGS, INC.,** 20 Precision Park, Keene, N. H.

# Stratopower Piston Pumps for Missile Applications Operate at High Temperature, Pressures, and Speed

TO meet the high performance demands, space limitations, and extreme operating conditions encountered in missile operation, Watertown Division of The New York Air Brake Company has developed a new series of compact, lightweight 10,000 rpm piston-type hydraulic pumps designed primarily for missile applications.

The 65 Series pumps, available in both constant delivery and variable delivery models, are up to 47 per cent lighter in weight. The 1/2, 1, 1 1/2, and 2 gpm constant delivery, and the 1/4, 1/2, and 1 gpm variable delivery pumps, rated at 1500 rpm, have excellent pumping characteristics at speeds up to 10,000 rpm and inlet pressures equivalent to 65,000 feet altitude. This, together with radical redesign, provides high horsepower to weight ratio—in some cases better than 4.5 horsepower per pound.

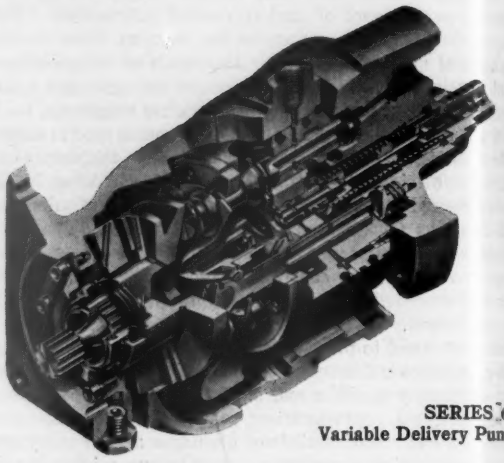
Ease of control, compactness, adaptability to automatic operation, and the necessity for dependable high pressure delivery have led to the extensive use of piston type pumps in the aircraft industry. In this service, exacting requirements of control in high speed aircraft call for pumps which possess these features—and the piston pump has them all.

Missiles of many types demand pumps capable of operating at higher speeds and temperatures than required in piston pumps designed for piloted aircraft. Missile pumps must operate at higher ambient temperatures while pumping fluid at elevated temperatures.

Both constant and variable delivery pumps in the 65 Series are of the positive-piston-return type. They are designed to afford the utmost simplicity consistent with operating requirements—fewer parts and extreme limitation in the weight of rotating parts.

Power capacity for a piston pump is proportional to the product of fluid pressure and displacement. Since weight and size are primarily functions of displacement, an increase in speed reduces pump size for the same horsepower.

The pumps will deliver fluid through a wide range of altitudes and speeds without pressurization so, in an emergency, if all pressurization is lost, the pumps will continue to operate without damage to themselves and at flow rates inversely proportional to altitude.

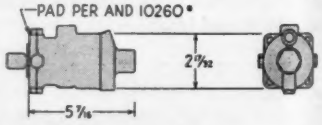


**SERIES 65**
**Variable Delivery Pump**

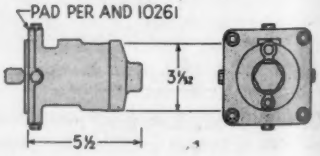
The new pumps are designed to meet military specifications MIL-P-7858 and MIL-P-7740 and even at higher speeds and corresponding higher flows, demonstrate excellent efficiencies over a wide range of temperatures and pressures. Pumps in the 65 Series have been designed specifically for, and are particularly adaptable to, missile applications.

Complete details of Stratopower Series 65 Pumps may be obtained from Watertown Division, The New York Air Brake Company, Starbuck Avenue, Watertown, N. Y., or from the company's International Sales Office, 90 West Street, New York 6, N. Y.

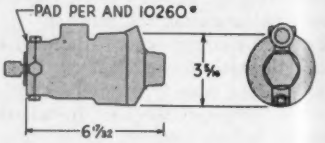
**VARIABLE DELIVERY MODELS**




**MODELS 65W 002**
**Rated Capacity: 0.25 gpm @1500 rpm.**
**Max. Continuous Speed: 10,000 rpm.**
**Weight: 3.5 lb.**

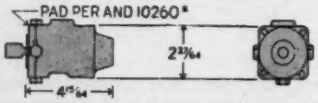



**MODELS 65W 005**
**Rated Capacity: 0.5 gpm @1500 rpm.**
**Max. Continuous Speed: 10,000 rpm.**
**Weight: 4.0 lb.**

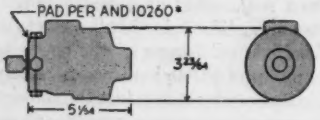



**MODELS 65W 010**
**Rated Capacity: 1.0 gpm @1500 rpm.**
**Max. Cont nuous Speed: 10,000 rpm.**
**Weight: 5.0 lb.**

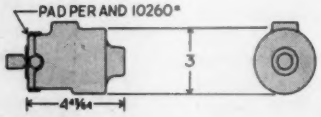
**CONSTANT DELIVERY MODELS**



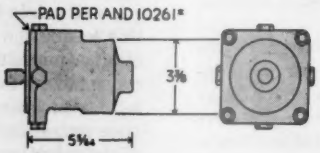

**MODELS 65F 005**
**Rated Capacity: 0.5 gpm @1500 rpm.**
**Max. Continuous Speed: 10,000 rpm.**
**Weight: 31 oz.**




**MODELS 65F 015**
**Rated Capacity: 1.5 gpm @1500 rpm.**
**Max. Continuous Speed: 10,000 rpm.**
**Weight: 4.0 lb.**




**MODELS 65F 010**
**Rated Capacity: 1.0 gpm @1500 rpm.**
**Max. Continuous Speed: 10,000 rpm.**
**Weight: 3.2 lb.**

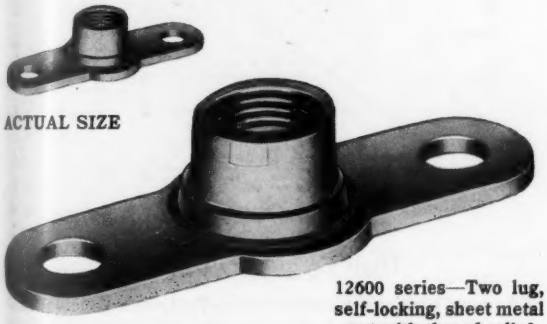



**MODELS 65F 020**
**Rated Capacity: 2.0 gpm @1500 rpm.**
**Max. Continuous Speed: 7,500 rpm.**
**Weight: 5.5 lb.**

Other mounting flanges and port arrangements available.

# Sheet Metal Self-Locking Nuts Reduce Weight and Size Problems in Assembly

DURING the past few years it has become increasingly apparent that manufacturers of aircraft components should give greater consideration to the assembly problems of rocket and missile manufacturers. Realizing the importance of this trend, Nutt-Shel Co., Inc., Glendale, Calif., manufacturer of self-locking anchor nuts and bolt and nut retainers, is doubling the production capacity of its plant with a new building. The new structure will provide 6000 square feet of space for new machinery to be used in the production of light weight, high strength sheet metal nuts.




**12600 series—Two lug, self-locking, sheet metal nut with thread relief**

### Characteristics of New Nuts

These high strength, low height nuts are fabricated from AISI 4130 aircraft quality steel. They meet requirements of MIL-N-25027 (ASG). Self-locking sheet metal nuts withstand temperatures up to 550 F and employ the triple lock locking method. They also incorporate a thread relief design which eliminates the need for the first shim. Since reduction of weight is a basic requirement, this design provides the ultimate answer for light weight AN362F-AN 366F series anchor nuts.

**3602 series—Miniature, two lug floating anchor nut**

Styles, employing these same advantages, will initially include one lug, two lug, corner, right angle, and miniature types. There will be a style for every requirement and in every case a significant reduction in weight and size. This has been made possible by improved design and by the use of sheet metal.

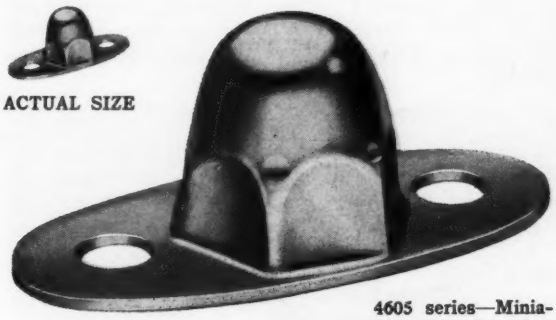
### Miniature Anchor Nuts

The importance of less weight and smaller envelope dimensions is evident in these minature anchor nuts.

3602 series. A two lug, floating, self-locking, anchor nut with a full 0.030 float from center. Available in cadmium plated steel and corrosion resistant steel for 550 F and 800 F, respectively.

4605 series. Fixed, two lug, self-locking, dome type anchor nut designed to eliminate wire chafing on screw threads; also provides for sealing area. Available in cadmium plated steel for 550 F temperature.

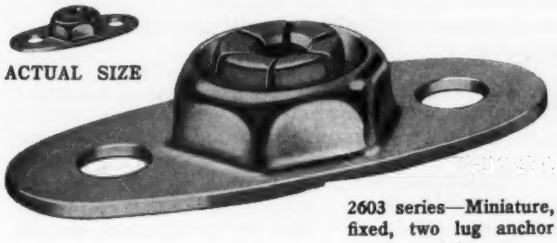
2603 series. Fixed, two lug, self-locking, anchor nut. Identical to 4605 series except it has no dome; it is available in cadmium plated steel for 550 F temperature.




**4605 series—Miniature, two lug, low dome anchor nut**

All are available in 4-40 and 6-32 thread sizes with cadmium plated steel for 550 F temperature applications and in corrosion resistant steel for 800 F temperature applications. They meet applicable requirements of Spec. AN-N-5 and AN-N-10.

The problem involved in creating a fastener that will join two surfaces satisfactorily is greatly simplified when we know all the facts involved in the application. It is especially desirable to work with potential customers when their plans are in the design stage. Frequently we have been able to provide a self-locking nut that not only met users' requirements but also reduced assembly costs. We invite comments from users of Nutt-Shel products and inquiries from those confronted with fastening problems.




**2603 series—Miniature, fixed, two lug anchor nut**

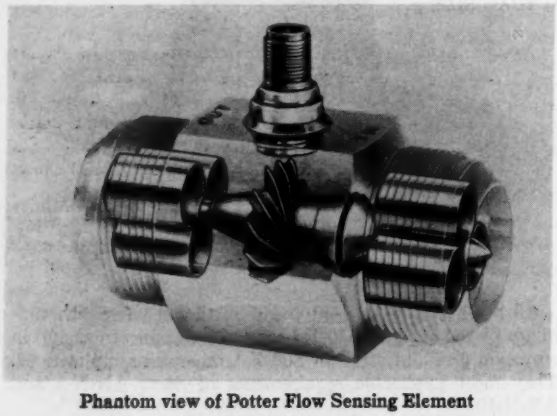
**NUTT-SHEL CO., INC.**
811 Airway, Glendale 1, Calif.

# Potter Progress Report

**Potter Aeronautical Company**
Rt. 22, Union, N. J. MU 6-3010

ALTHOUGH it is now widely adopted for general industrial use where high precision in flow measurement or control is critical, the Potter Flow Sensing Element was originally developed specifically for the rocket industry and is still regarded as the standard instrument for measuring the flow of liquid fuel and oxidizers. As a matter of historical interest, some of the first Potter Flow Sensing Elements built to the present design were used by Reaction Motors, Incorporated, in the Viking rocket program; and similar units were used by Bell Aircraft in the oxygen tank balancing system of the famous X-1.

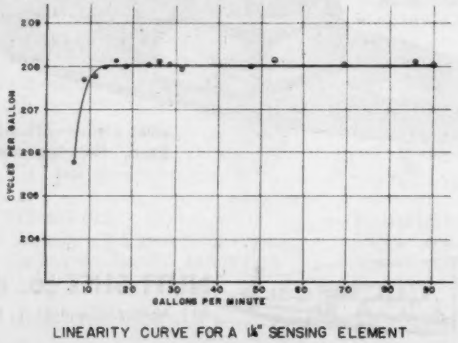
Recent developments in the design of Potter Sensing Elements and associated equipment have further extended their usefulness in the jet engine and rocket fields. This report attempts to list some of the more important advances for the benefit of those interested in flow measurement, air speed measurement, tachometry, and the telemetering of these variables.



**Phantom view of Potter Flow Sensing Element**

## New Flow Sensors

The Potter Flow Sensing Element, which has long been familiar to those engaged in research, development, and production testing in the rocket and aircraft engine fields, is now available in a greater number of sizes, ranging from the new 1/8 in. unit which has a minimum capacity of 0.05 GPM, to the 6 in. element which will handle over 3000 GPM. New materials of construction and new machining techniques now make possible the accurate metering of halogen compounds such as HCl, and also permit operation at temperatures up to 450°F with no special precautions for cooling the pickup coil.

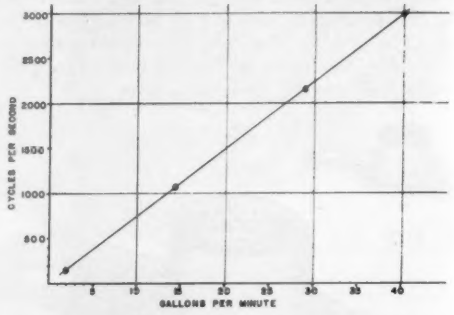



LINEARITY CURVE FOR A ⅛" SENSING ELEMENT

## Special Elements

In addition to standard units, special elements can also be fabricated to customers' specifications to solve difficult installation problems.

Specialized requirements in rocket research have brought about the development of two new Potter Flow Sensors, both of which employ the familiar "floating rotor" principle.




HIGH FREQUENCY FLOW SENSOR

## High Frequency Units

The need for higher response speeds for transient flow measurement has necessitated the use of flow sensors having substantially higher output frequencies that can be obtained with the conventional hub-mounted magnet. Through the use of a reluctance coil pickup, together with a rotor machined from series 400 stainless or some other magnetic material, it is now possible to obtain output frequencies as high as 3000 cps.

In addition to improved performance with high-speed instrumentation, the higher cycles-per-gallon constant of this unit gives considerably more accurate readings of flow rate when used with an EPUT meter.

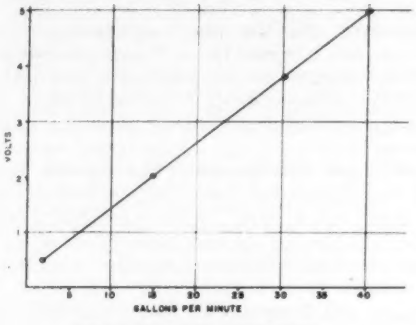
**Self-generating flowmeter system, consisting of sensing element and indicator, requires no power for operation**

## For Noisy Locations

A unit having special magnetic shielding is also now available for use in locations where an appreciable amount of magnetic interference is encountered. Producing the same frequency output signal as the conventional Potter unit for measuring either flow rate or total, noise generation is minimized and dependability increased.

## Self-Generating Flowmeter

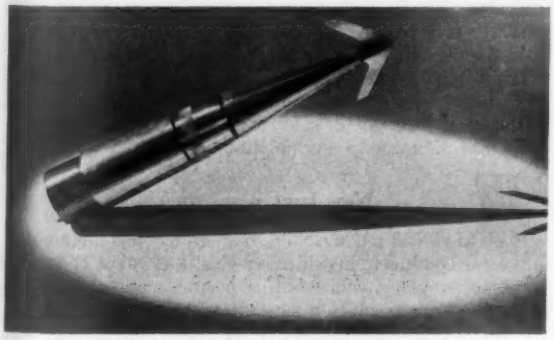
The self-generating Potter Flow Sensor is designed particularly for airborne applications in which the flow rate is to be telemetered. The output, 0–5 volts, is directly proportional to the rate of flow. While slightly less accurate than the conventional system employing a frequency converter, the weight reduction achieved through the elimination of electronic equipment offers a clear advantage. The self-generating unit also makes possible a relatively inexpensive monitor system for high-low alarm action and for flow indication where no power supply is available.




SELF GENERATING FLOWMETER

## Ratio Control

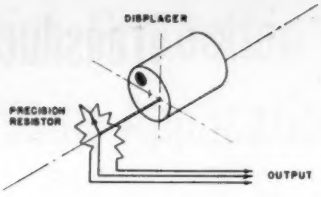
Since the output of the Potter Flow Sensing Element is inherently linear with respect to flow over a wide range of operation, the applicability of this type element to ratio control applications has long been realized. A total-fuel total oxidant ratio control system, operating on a digital basis, has been devised for obtaining the maximum total impulse from a rocket engine through the control of the ratio of fuel and oxidizer from the supply tanks to the combustion chamber. The system does not accumulate error due to short-time disturbances, since it has a memory dating from the instant combustion is started. Tests have shown that this system is easily capable of maintaining a pre-set ratio within $^1/_2$ per cent.



**Sensing head for airspeed indicator**

## Air Speed Indicator

Operating with high accuracy at subsonic and supersonic airspeeds, a new primary sensing element now undergoing field tests produces an a-c voltage whose frequency is directly proportional to airspeed. This signal can be read as airspeed or it can be compared with the output signal from a Potter flow sensor measuring fuel consumption in order to obtain a reading directly in air miles per gallon. Because of the high accuracy obtained, the new device is expected to find acceptance as a wind tunnel standard as well as for flight applications.




DENSITY DETECTOR UNIT

## Mass Flowmeter

The need for separate sampling and for density measurement in order to obtain a reading in terms of mass flow is now eliminated through the new Potter Density Detector Unit. Employing an eccentrically mounted, totally submerged displacer, the unit produces a resistance change which is directly proportional to fluid density over a range from 0.6 to 0.9. This is transmitted, as a correction signal, directly to the flow indicating instrument which automatically indicates flow in lb per hr or other mass units. The Density Detector Unit can easily be added to existing systems.

## Total Flow Measurement

Reading of total flow with high accuracy is accomplished through the use of an electronic counter to totalize the output pulses of the sensing element. The Model 21 Totalizer, an all-purpose electronic counter, operates from an input signal as low as 10 millivolts at output frequencies to 1 kc. The indicated total is multiplied by a constant conversion factor to obtain the actual flow in volumetric units.

The Model 25 Flow Digitizer is also available for direct reading of total flow. This instrument has the same operating characteristics as the Model 21, except that it includes a push-button computer which automatically converts the total number of input pulses to a direct reading of total flow.

**Electronic counter for total flow indication registers up to 99,999,999 pulses at frequencies to 1 kc**

## Wide-Range Precision Flow Indicator

Flow measurement with extremely high accuracy over a wide range of operation is now possible through the use of a multichannel frequency converter which is mounted directly inside the case of a precision indicating electronic potentiometer. This permits a single instrument to be used with a number of sensing elements graduated progressively. To obtain very high readability, the range of single sensing elements can be read on two scales. Switching can be either manual or automatic, and provision is made for the automatic actuation of control valves to direct the flow through the proper sensing element.

Potter laboratory-type frequency converters, used in flowmeter and tachometer systems, have also been improved through recent design modifications to permit their use in multiple-element systems. Other new modifications have improved linearity, stability, and tube life.

# Transducers for Missile Control

GEORGE TURNER SENSENEY

Vice-President, Engineering

Rahm Instruments, Inc.,

12 West Broadway, New York 7, N. Y.

THE performance of a guided missile or pilotless aircraft is limited by the excellence of its control instrumentation. RAHM INSTRUMENTS, INC., is exclusively devoted to the development, evaluation, and production of sensing elements for incorporation in the guidance systems of airborne vehicles.

## Potentiometer Transducers

The most widely accepted measuring devices in the missile field are transducers in which an elastic element such as a corrugated diaphragm, a bourdon tube, or a seismic system actuates the brush of a precision potentiometer.

The popularity of potentiometer instruments among the designers of missile control systems is readily understandable when the following advantages are considered:

(1) **Accuracy:** A well-constructed unit will provide readings in voltage ratio vs. the quantity to be measured with errors limited to tenths of a per cent.

(2) **Stability:** The inherent characteristics of potentiometers provide that changes in supply voltage or ambient temperature do not affect the output accuracy since it is in terms of ratio. Even wear, in the order of a million cycles, causes little increase in error.

(3) **No Ancillary Equipment Required:** The resistance windings are at low impedance and supply voltages may be comparatively high, obviating the necessity of vacuum tube amplifiers with their attendant difficulties and space-weight disadvantages.

(4) **Versatility:** The potentiometer resistances may be wound and/or shunted to give output plots linear with pressure or linear with a function of pressure such as airspeed or altitude; logarithmic or exponential outputs are also readily available.

Front view of typical pressure transducer

## Rahm Construction Features

While potentiometer transducers are old in concept and no differences in their basic design have appeared in recent years, the requirements for their performance are becoming more stringent. Military specifications call out increasingly severe environmental conditions, and the space-weight engineers require lighter and smaller units. RAHM INSTRUMENTS has concentrated its effort toward the development of instruments which meet these demands. Following are some of the steps that have been taken in this direction.

**Temperature:** All the elastic members such as diaphragms are now fabricated from Nispan since its modulus of elasticity change with temperature is practically zero. Special alloys, stress-relieving of various members, and the use of compensating elements have reduced the temperature errors.

**Vibration and Acceleration:** The moving system of RAHM transducers has been compensated dynamically in all three major axes. When operational vibration conditions are beyond the endurance limits of the elastic elements, standard vibration elimination mounts are provided.

**Corrosion and Fungus:** All fungus nutrient materials have been eliminated. The cases and major parts are made of aluminum and are anodized to gain maximum protection against salt spray and other corrosive mediums.

**Wear:** While the life expectancy of a missile is very short, it is desirable to incorporate a maximum durability in instruments which must be extensively operated during test and calibration. RAHM uses platinum-tungsten resistance wire with precious metal brushes. Moving parts and bearings have been reduced to a minimum; in fact, all pressure transducers whose range is below 140 psi have only one moving element.

**Resolution:** Resistance wire whose diameter is measured in ten-thousandths of an inch is used to assure that the maximum number of turns per inch are provided; for while the resolution of the elastic elements is infinite, the actual resolution of a potentiometer transducer is the reciprocal of the total number of turns.

**Seals:** All RAHM transducer cases are sealed with specially selected "O" rings. Each instrument is tested for leaks over its range and at both temperature extremes.

**Mountings:** Any RAHM instrument may be provided with three different mounting attachments so that it may be installed from either side through a plate or bulkhead, or surface mounted in any position.

## New Instruments

RAHM INSTRUMENTS has under development a universal conducer, in which an elastic element controls a servomotor system, which in turn positions, at the customer's option, a high resolution potentiometer, a synchro, or a resolver. This unit will also be available with a shaft output whose angular position will be proportional to the quantity to be measured, for attachment to the user's own transmission device.

## Special Instruments

RAHM INSTRUMENTS solicits inquiries for the development of special devices provided their principal function is associated with the measurement or control of pressure. We have constructed a number of special units for our customers, such as dual pressure transducers for measurement of depth and water speed, multirange dual units for altitude and airspeed, and an antenna pitch controller.

# Combining Shock and Vibration Protection for Jet Aircraft and Guided Missile Application

MANY vibration mountings that are currently being installed in today's high performance jet aircraft and missiles for the protection of electronic components have been proven to be completely inadequate for their purpose. These mountings are designed to meet existing military specifications such as MIL-C-172B which were based on preliminary developmental work preceding and during World War II and which have been outmoded by the rapid advances in the aviation field.

A low frequency mount with a natural frequency of 8 cycles per second may be adequate for vibration over 15 cycles per second. However, under shock loadings of launching, severe acceleration or abrupt change of direction, shock may be amplified by a factor as great as 6. This can do more damage than good in jet aircraft or missiles. Such an "isolator", conforming to Military Specifications MIL-C-172B in every respect, can subject equipment to 30 G of shock force when the aircraft is experiencing only 5 G of impact over the airframe.

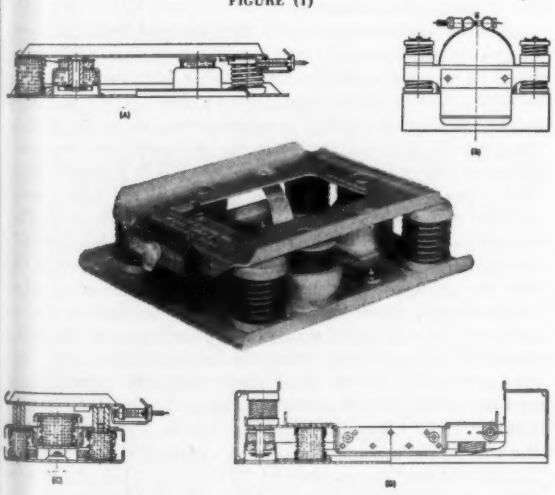
These findings have been corroborated by a reliability program instituted by one of the larger airframe manufacturers. Exhaustive testing of available "isolators" demonstrated that of those designed to existing specifications, none was capable of providing both shock and vibration protection.

To meet today's performance requirements an ideal mounting would have a natural frequency of 4 or 5 cycles per second and attenuate shock forces of any anticipated magnitude. However, such a mounting design is completely impractical in view of the space limitations in modern airborne compartments. A compromise was obviously necessary.

It was found that in the vibration range of most jet aircraft and missiles, there exists an area of relatively low energy level in the vicinity of 20 cycles per second. A mounting system designed to take advantage of this fact that would isolate higher frequency vibration and not amplify shock, offers the most promising compromise.

A mounting system with a natural frequency of 25 cycles per second was engineered and demonstrated to reduce shock amplification to a factor of 2. Vibration amplification occurred at a non-critical point for the equipment.

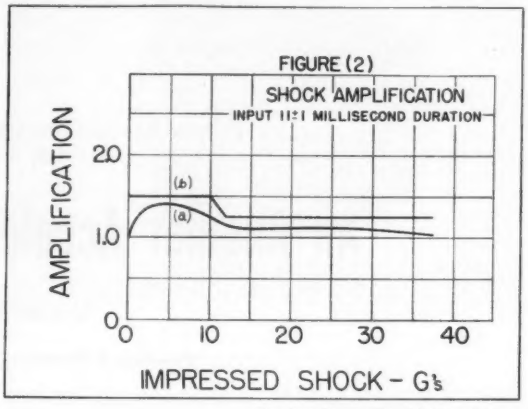
FIGURE (1)



One of the prime prerequisites for this type of mounting system is that there will be no abrupt change in spring rate as the mounting is deflected. The restrictions on allowable sway space in most aircraft installations precluded adoption of a soft spring rate which would meet existing vibration specifications, since this would result in excessive deflection under shock or overload.

Robinson Aviation, Inc., engineered mounting systems achieved the necessary compromise between shock and vibration isolation by utilizing Robinson's exclusive load carrying resilient elements consisting of fabricated stainless steel wire cushions and shock pads. Their use enables ideal distribution of resilient and snubbing elements without awkward shapes or overlarge systems. Non-linearity of their spring rate and damping combined with a wide environmental tolerance have enabled these systems to withstand steady state and suddenly applied overloads. These characteristics result in smooth, highly damped cushioning of large excursion or high energy disturbances without abrupt "bottoming", while retaining the greatest possible measure of isolation for smaller amplitude steady state vibration.

Development of three basic design configurations utilizing these principles led to the immediate development and production of forty-seven different mountings for application in our latest jet aircraft and guided missiles. The three basic approaches are shown in Figure 1 as types A, B and C. Type D is similar in principle to type C. Further




*Courtesy Chance Vought Aircraft, Inc.*

research is currently being conducted on a new principle which offers considerable promise for these applications. The four typical variations shown in Figure 1 are discussed below.

Type A was developed in the conventional base type configuration and is applicable to lighter loads in normal form factors. It utilizes conventional Robinson MET-L-FLEX load carrying cushions which are inherently non-linear. Large, relatively soft motion limiters are incorporated which carry no static load but function under dynamic loads in all directions. When tilted, this mounting provides vibration isolation superior to conventional designs. Shock performance (Curve A) is compared with realistic design specification requirements (Curve B) as shown in Figure 2.

Type B utilizes double-acting, multi-directional MET-L-FLEX cushions which have equal load carrying and shock absorption qualities in all directions and at all angles. This configuration is readily adapted to the center of gravity cradle type of suspension wherein the resilient members are situated so that they are in the same horizontal plane as the equipment center of gravity. This eliminates rocking or tipping which might occur with a base mounting. The system functions equally well in any position or attitude.

Type C has the cushions situated so that they oppose each other while providing equal energy absorption capacities in all directions. The non-linear spring rate assures maximum capacity for dynamic overloads which may originate from any angle. This type of design approach increases the load carrying capacity of the mounts.

Type D also utilizes the concept of opposed sets of cushions. Here, each cushion in the lower set opposes one in the upper. The motion limiting devices, incorporated as separate assemblies, take over only after considerable compression of the non-linear cushions. This provides additional increased stiffness for the attenuation of impact forces. For increased stability this design is readily adaptable to the center of gravity type suspension system.

The design objectives precluded the use of unit type "shock mounts" or so called "isolators". Only through the use of engineered mounting systems was it possible to achieve a high and uniform standard of performance and reliability. The features inherent in the all-metal load carrying cushions of fabricated wire, combined with basic Robinson design principles, have enabled the engineered systems to cope with the technical and production problems.

**ROBINSON AVIATION, INC., TETERBORO, NEW JERSEY**

***Vibration Control Engineers***

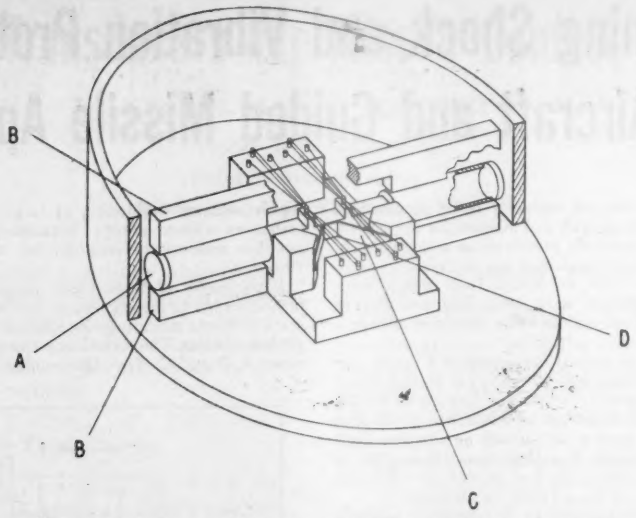



**Fig. 1 Isometric view of Statham Liquid Rotor Angular Accelerometer***
A, paddle; B, baffle; C, flexure; D, strain-sensitive filaments
* *Patents Pending.*

# An Angular Accelerometer for Guidance

GILBERT N. ROSA[1]

**Statham Laboratories, Inc., Los Angeles, Calif.**

HIGH velocity aircraft and missiles are frequently guided by controlling the angular velocity of the control surfaces. To accomplish this guidance effectively, the primary element of the auto-pilot servo should detect one order higher than angular velocity, that is, angular acceleration. The detection of this angular acceleration is tradionally achieved by employing a rate gyro with a differentiating network in the output of its pick-off. Much simpler is to use an angular accelerometer directly to override the rate gyro, thus eliminating the necessity for a differentiating network; but past experience with conventional angular accelerometers has not been encouraging because of their undesirable sensitivity to linear acceleration and to angular velocity. Both of these handicaps have been overcome in a radically new invention which has been developed at Statham Laboratories.

Fig. 1 shows the essentials of a Statham angular accelerometer. The novelty of this angular accelerometer is that its rotor consists of liquid only. When the case is subjected to an angular acceleration, the inertial forces will cause the liquid to rotate and develop a hydrostatic pressure against the paddle as the liquid is forced between the paddle and the baffles. The paddle will deflect angularly until the elastic restraint of the flexure and the pick-off balances the forces on the paddle. This novel construction has been adapted to both unbonded strain gage and inductive pick-offs.

The advantages of the Statham liquid rotor angular accelerometer design are apparent after a careful perusal of Fig. 1. Since the liquid mass serves as the rotor, the weight of the paddle which must be supported along the sensitive axis can be made extremely low. In the construction of low range, rigid rotor angular accelerometers, because of the weight of the rotor, ball bearings are frequently employed to contain the rotor spindle. In the liquid rotor design, weak flexures are practical since only a small, rigid mass need be suspended. Thus, the resolution of Statham liquid rotor angular accelerometers is limited only by the noise level of the electrical pick-off and its associated circuitry.

At first glance, it might seem that the paddle itself merely acts as a rigid rotor immersed in a damping fluid and, hence, forms an angular accelerometer, albeit a high range one. In addition, the lack of radial symmetry will make such an instrument especially susceptible to angular velocity errors (Ref. 1). Fortunately, it is not necessary for the paddle to have any apparent mass; all that is required is that it be structurally rigid. Accordingly, the paddle is constructed as a hollow cylinder with sealed ends so that its apparent mass, when immersed in the liquid of the rotor, is negligible. The use of a buoyant paddle also eliminates the necessity for careful balance to minimize the sensitivity of the instrument to linear accelerations. Ordinary manufacturing tolerances on the symmetry of the paddle are usually sufficient to insure an adequate balance of the extremely low apparent mass. Linear acceleration errors along three mutually perpendicular axes are as low as 0.05 per cent full scale per g. The angular velocity error along the sensitive axis is negligible. Along the worst axis, the angular velocity sensitivity is of the order of 0.03 rad/sec$^2$ per rad/sec at 10 rad/sec. Despite the use of weak supporting springs, it can be appreciated readily that the low mass of the paddle insures its relative insensitivity to g shock, an advantage not usually enjoyed by low range, heavy, rigid rotor angular accelerometer designs, especially when the rotor is mounted by means of a leaf-hinge type Cardan suspension.

Statham liquid rotor angular accelerometers are available in ranges from $\pm$ 1.5 to $\pm$ 3,000 rad/sec$^2$.

[1] Director, Special Projects Division.

## Reference

1 "Angular Accelerometer Errors Arising From a Bar-Type Design of the Seismic Mass," by G. L. Smith, *Review of Scientific Instruments*, vol. 23, February 1952, p. 97.

# Gas-Generating Cartridges for Auxiliary Power Units

T. GAYNOR BLAKE

Olin Mathieson Chemical Corporation

IN today's high-speed aircraft and in the guided missile field, many power requirements call for a large amount of energy over a relatively short period of time. Although there are many ways of supplying this energy, the simplest means in many instances is the use of a solid propellant gas-generating cartridge. This method generally results in the additional attractive feature of saving airborne weight.

## Four General Uses

A gas-generating cartridge can be used in four general ways:

1. To drive an auxiliary turbine.
2. To actuate a piston.
3. To pressurize a system.
4. To furnish direct thrust.

The illustrations on this page show a typical application of a gas-generating cartridge for actuating an auxiliary turbine which is used to crank a jet engine in starting.

Fig. 1 shows an Olin Mathieson "packaged power" cartridge. This cartridge, when placed in the breech of a General Electric gas turbine starter (Fig. 2) and ignited electrically by a switch in the pilot's cockpit, furnishes gases to accelerate the small high-speed turbine wheel in the starter.

The duct work and nozzle which direct the gaseous reaction products to impinge on the turbine blades are not shown in this illustration. The exhaust duct is shown at the top center of the drawing.

The turbine wheel is connected through a gear train and clutch to a mechanism which engages a member on the Curtiss-Wright J65-W5 engine shaft.

## Starter on Each Engine

Fig. 3 shows a Martin B-57 light bomber on which this starting system is employed. A starter is used on each engine and is enclosed in a streamlined "bullet nose" in the center of the engine air intake opening.

The solid propellant charge for the jet engine starter was designed to deliver an essentially uniform flow of gases throughout a burning time of approximately 10 seconds.

The constant torque provided accelerates the jet engine rotor to "starter cut-out" speed without excessive stressing of the rotor components. The lightweight construction of the starter breech assembly necessitated a propellant charge design which would operate at a nominal breech pressure of 1100 psi with a maximum allowable pressure of 1500 psi, over the entire temperature range of minus 75 degrees F to 150 degrees F.

The performance of the Olin Mathieson starter cartridge has proved the dependability and desirability of this method of starting gas turbines. It represents the first operational application of a solid propellant charge to this task in the United States and is the only jet engine starter cartridge now in quantity production.

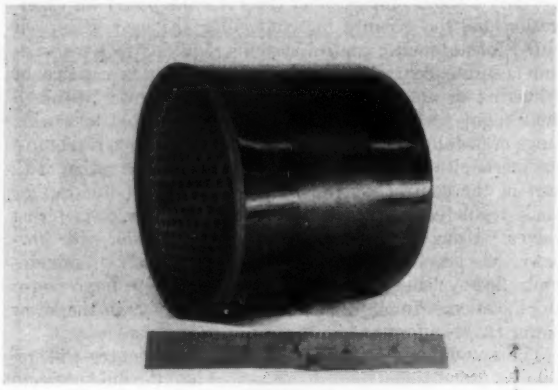


Fig. 1

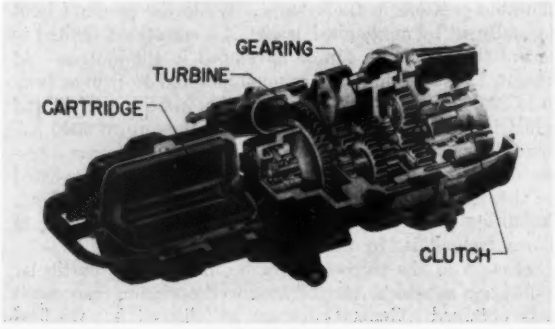



Fig. 2

Fig. 3

# Hydraulic Motors for Automatic Control

LEROY R. TAYLOR

Project Engineer

VICKERS INCORPORATED

SINCE the hydraulic motor, in most applications, absorbs only a small proportion of the available power for acceleration and the balance for controlling the load, it is well suited for automatic control systems requiring fast response and accurate control. The hydraulic motor is capable of delivering or absorbing a large amount of power within a small, light package, and can be readily adapted to a wide range of installations. Because of its light weight, it requires less mechanical support than other types of equal rating. As part of the control system, the speed of the motor can be easily regulated by variable displacement pumps or metering valves. Using these components in combination with low-power electrical torque motors and pilot valves, remote-controlled systems can be readily obtained with large power amplification. In addition, the high sensitivity in the lower power ranges affords a high degree of accuracy.

The amount of torque that the hydraulic motor will develop is proportional to its displacement and the fluid pressure applied or developed. This torque is independent of the speed at which the motor is rotating. The limit on the torque available for a given size motor depends, in turn, upon the allowable pressure in the system. While the pressure limit is usually set by mechanical design, it is sometimes limited to control the maximum torque developed in the system. At present, hydraulic motors are manufactured to deliver from 15 to 24,000 in.-lb at 1000 psi. Motors in both aircraft and industrial designs are available for pressures up to 5000 psi. Some design information of particular interest to servo system design engineers is given in Table I. The ratings listed are theoretical and refer to the motors operated at no-load. Certain items such as acceleration and time constant will, of course, be modified by the characteristics of the load.

Selection of the correct hydraulic motor for a particular application should be carefully made if optimum response is to be obtained. General rules can be followed, but the final choice must depend upon detailed calculations. The motor, however, must be capable of meeting these three basic conditions:

(1) The speed range (ratio of the maximum to the minimum speed) that the motor is capable of must be greater than that required by the load.

(2) The maximum allowable speed of the hydraulic motor must be greater than the maximum speed required of the load multiplied by the gear ratio.

(3) The motor must supply more torque than the sum of that required by the load (as reflected through the gear train) and that required to accelerate the hydraulic motor.

Speed range is the first operating characteristic that should be considered. Hydraulic motors have a minimum smooth speed of about 10 rpm, regardless of motor size. Hydraulic motor speed range is then the ratio of the maximum rated speed of the motor divided by 10 rpm. For standard production aircraft type motors, this ratio varies from 910:1 for the smallest to 312:1 for the largest. In many applications, components can be designed to reduce the minimum speed and thereby extend the speed range by a considerable margin over these figures. The speed range, therefore, determines the maximum motor sizes that can be used for a particular application. If the horsepower requirements are greater than that of the motor selected on the basis of speed range, then two or three motors must be used in parallel.

The limiting 10 rpm speed also regulates the minimum gear ration that can be used. For example, if a slow speed of 0.36 deg/sec or 0.06 rev/min is required of the load, the gear ratio for this application is 10/0.06 or 167. Speed range and slow, smooth speed thus determine the maximum motor size and the minimum gear ratio.

Actual hydraulic motor size will be determined from the horsepower, acceleration, and speed requirements of the load. Generally, the horsepower controls the minimum motor size while the speed determines the maximum that can be used.

The selection of a hydraulic motor for a particular application can be made by the use of the graphs shown in Fig. 1. To use the graphs, the horsepower required by the load and the ratio of the required load acceleration to load velocity must be known. By entering the graph with the horsepower, the displacement can be determined where the horsepower line intersects with a point on the selected acceleration/velocity curve. Any motor which has a displacement greater than this amount is suitable for the application, providing it meets the speed range requirements of the load.

Size of the hydraulic motor for a particular application can be selected by the use of the graphs and the speed range criteria. Where two or more motors are suitable, further calculation should be made to select the one which gives the best response. Experience has shown, however, that the smallest size motor will generally give the maximum response.

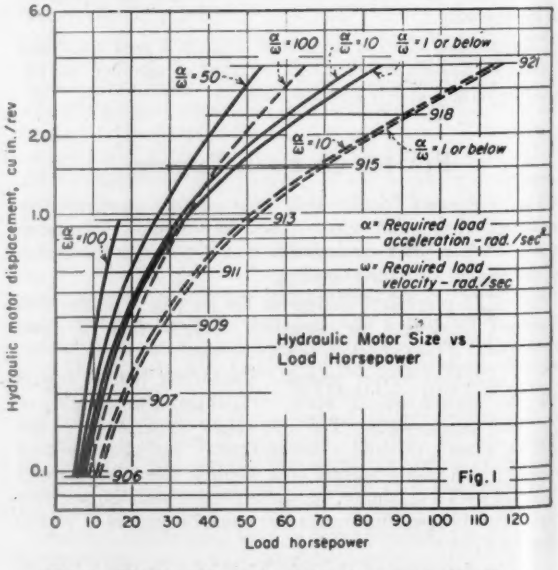



**Fig. 1 Relationship of load horsepower, motor displacement, and load inertia to determine required motor size. Curves representing the ratio of required load acceleration to required load velocity are shown by dashed lines for the 4,500 psi maximum pressure range and by solid lines for the 3,000 psi range**

When the acceleration-velocity ratio is greater than 10, some consideration should be given to using two or more motors instead of one. A high ratio shows that a larger percentage of the power will be used in accelerating the inertia of the motor. That is, the motor inertia becomes an appreciable portion of the total inertia. In these same applications, the gear inertia also assumes a more important proportion of the total. For this reason, a close approximation of the gear inertia is required. To use the graphs for two or more motors, the horsepower should be divided by the number of motors required and used as before.

Vickers Incorporated has cooperated in the design of numerous servo systems which utilize hydraulic motors. Technical assistance to the user in the selection of a proper size motor with suitable performance is always immediately available.

**Table I—Tables for Typical Aircraft Design Hydraulic Control Pumps and Motors.**

Note that the items are qualified as representing either fixed or variable displacement pumps or motors, or both.

| ITEM DESCRIPTION | MODEL DESIGNATION | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 906 | 907 | 909 | 911 | 913 | 915 | 918 | 921 |
| Displacement, cu in./rev[1] | 0.095 | 0.188 | 0.367 | 0.598 | 0.950 | 1.519 | 2.349 | 3.671 |
| Moment of Inertia of Rotating Group[1] | | | | | | | | |
| lb-in$^2$ | 0.052 | 0.144 | 0.431 | 0.946 | 1.95 | 4.09 | 9.53 | 15.74 |
| lb-in-sec$^2$ | $1.35\times10^{-4}$ | $3.72\times10^{-4}$ | $11.1\times10^{-4}$ | $24.5\times10^{-4}$ | $50.5\times10^{-4}$ | $106\times10^{-4}$ | $247\times10^{-4}$ | $408\times10^{-4}$ |
| Maximum Continuous Speed Rating, rpm[1] | 6060 | 4840 | 3860 | 3280 | 2820 | 2820 | 2400 | 2080 |
| Maximum Intermittent Speed Rating, rpm[1] | 9100 | 7245 | 5800 | 4920 | 4230 | 4230 | 3610 | 3120 |
| Torque at[3] | | | | | | | | |
| 3000 psi, lb-in. | 45.4 | 89.7 | 175 | 286 | 459 | 735 | 1122 | 1753 |
| 4500 psi, lb-in. | 68.1 | 135 | 263 | 428 | 681 | 1088 | 1683 | 2629 |
| Power at[3] | | | | | | | | |
| max continuous, hp | 4.4 | 6.9 | 11 | 15 | 20 | 32 | 43 | 58 |
| max. intermittent, hp | 9.8 | 15 | 24 | 34 | 46 | 73 | 96 | 130 |
| Acceleration at[3] | | | | | | | | |
| 3000 psi, rad/sec$^2$ | $3.4\times10^5$ | $2.4\times10^5$ | $1.6\times10^5$ | $1.2\times10^5$ | $0.91\times10^5$ | $0.69\times10^5$ | $0.46\times10^5$ | $0.43\times10^5$ |
| 4500 psi, rad/sec$^2$ | $5.1\times10^5$ | $3.6\times10^5$ | $2.4\times10^5$ | $1.7\times10^5$ | $1.35\times10^5$ | $1.03\times10^5$ | $0.68\times10^5$ | $0.6\times10^5$ |
| Min. Rev. to Stop From Max. Intermittent Speed[3] | 0.141 | 0.125 | 0.122 | 0.124 | 0.116 | 0.145 | 0.167 | 0.132 |
| Time Constant, sec[3] | 0.0019 | 0.0021 | 0.0025 | 0.0030 | 0.0033 | 0.0047 | 0.0054 | 0.0051 |
| Torque[2] Inertia for:[3] | | | | | | | | |
| 3000 psi, lb-in/sec$^2$ | $1.5\times10^7$ | $2.2\times10^7$ | $2.8\times10^7$ | $3.4\times10^7$ | $4.1\times10^7$ | $4.9\times10^7$ | $6.1\times10^7$ | $7.2\times10^7$ |
| 4500 psi lb-in/sec$^2$ | $3.5\times10^7$ | $4.9\times10^7$ | $6.3\times10^7$ | $7.3\times10^7$ | $9.2\times10^7$ | $11\times10^7$ | $14\times10^7$ | $16\times10^7$ |
| Volume Under Compression[1] | | | | | | | | |
| Fixed Displ., cu. in. | 0.114 | 0.226 | 0.443 | 0.719 | 1.14 | 1.82 | 2.80 | 4.41 |
| Variable Displ., cu. in. | 0.285 | 0.564 | 1.101 | 1.790 | 2.85 | 4.56 | 7.05 | 11.01 |
| Leakage[1] | | | | | | | | |
| Cu. in./sec./1,000 psi. | 0390 | .0772 | 0.150 | 0.245 | 0.390 | 0.620 | 0.960 | 1.50 |
| Weight, lb[2] | 2.6 | 3.6 | 5.9 | 8.5 | 12.0 | 17.6 | 24.5 | 30.1 |
| Max. Continuous Power hp[3] | 1.70 | 1.93 | 1.86 | 1.76 | 1.67 | 1.82 | 1.75 | 1.76 |
| Weight lb | | | | | | | | |

Notes: 1—Pumps and Motors, either fixed or variable displacement.
2—Pumps and Motors, fixed displacement only. 3—Motors only.
In model designations, first digit refers to number of cylinders in rotating group; Last two digits are piston diameter in 32's of an inch.

# Servo Pumps and Servo Valves

NORTON WILLIAMS

**Assistant Manager, Aircraft Products Sales Dept.**

**VICKERS INCORPORATED**

TWO general ways in which hydraulic control of servo circuits may be considered are:

1. Source control.
2. Line control.

That is, (1) the direction and amount of fluid flow may be controlled at the source at which the hydraulic power is generated—for example, by use of a servo pump; or (2) a constant pressure source may be established and a metering valve placed in the main power line between this source and the load—for example, electro-hydraulic servo metering valves.

1.1 Vickers has a very successful history of pioneering, design, and production in the hydraulic servo pump field. Most of these pumps have been of the electro-hydraulic type. A Vickers unit of this type is an electrically controlled, variable-delivery, positive displacement, hydraulic pump. The combination of this pump and a rotary or linear hydraulic motor forms an electrically controlled hydraulic transmission, with the motor acting as the output member. These transmissions are usually designed especially for use in remote control operations, and in high-response servo systems employing electrical feedback. However, some of the Vickers servo pump units are designed so that they are entirely mechanically controlled.

1.2 The transmission may be considered as a power amplifier when viewed from the electrical signal input of a few watts to the mechanical power output of several thousand watts. Various sizes of transmissions have been built, having output capacity ratings from one to 400 horsepower.

1.3 The basic power input to the transmission may be an electric motor, auxiliary drive pad on an airplane engine, air turbine, hydraulic motor, or other prime mover which will provide adequate power and substantially constant speed for driving the servo pump unit.

1.4 The direction and rate of fluid flow from the servo pump unit are controlled by application of a very low power signal to an electrical torque motor, which is usually included as an integral part of the pump unit assembly. Acceleration, velocity, position, and direction of motion of the output member and the load are under control of this electrical signal and such feedback circuits as may be desired. Speed changes are smooth and stepless.

1.5 The servo pump unit and its associated hydraulic motor are designed to have a high power-to-weight ratio, high torque-to-inertia ratio, low inertia of rotating parts, high-resonant frequency, reliability, and versatility of application. The hydraulic motor is normally of a fixed stroke design; however, variable motors are available. In general, this difference in hydraylic motors will determine the operating characteristics of the transmission as follows:

*A.* A fixed stroke hydraulic motor gives:

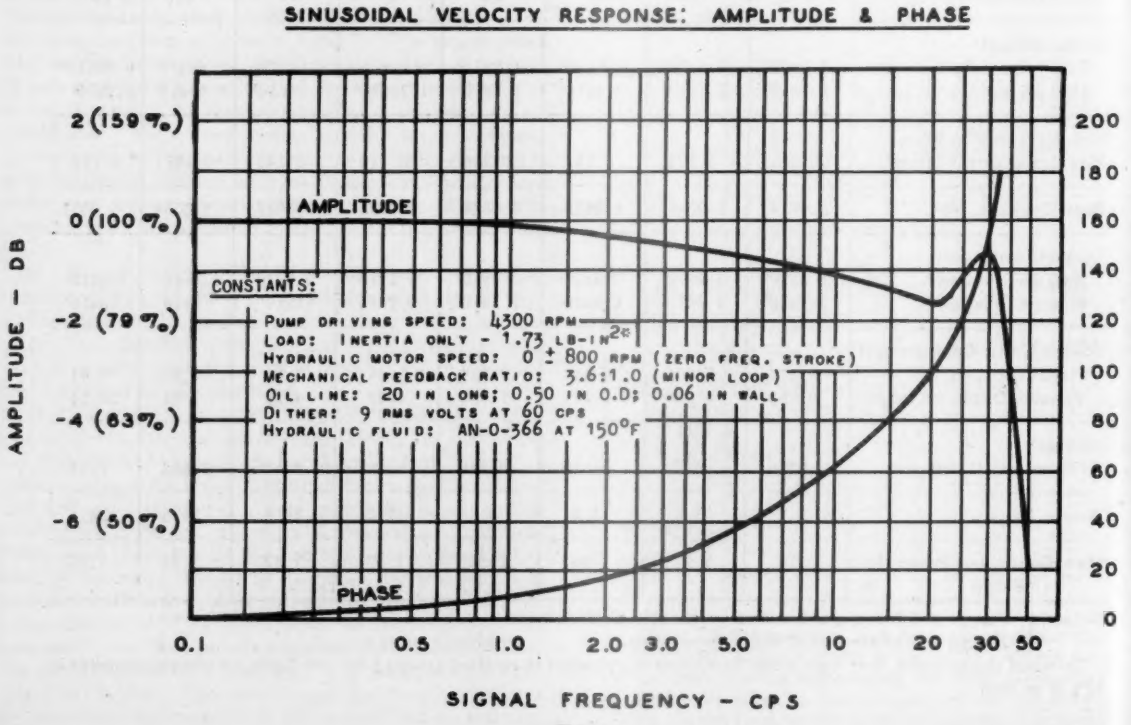



Fig. 1

1. Torque directly proportional to pressure.
2. Speed directly proportional to flow.

Constant torque will be obtained if pressure is held constant.

*B.* A variable stroke hydraulic motor gives:

1. Torque directly proportional to motor yoke angle when pressure is constant.
2. Speed directly proportional to flow and inversely proportional to motor yoke angle.

Constant speed will be obtained if flow varies in direct proportion to motor yoke angle.

1.6 The power loss for control purposes is low in a servo pump unit because metering valve action is confined to a low-power level hydraulic system. This is the stroking system. It is a part of the pump unit, and is usually designed to operate at pressures of 100 to 300 psi. The stroking system controls the amount and direction of stroke of the main power pump, which may operate at pressures up to 3000 or 4000 psi. Pressure drop across the ports of a metering valve, with its inherent losses, is avoided in the main power system. That is, the final power output from the pump is not dependent upon pressure-drop methods of control, but is determined by the amount of flow which the stroking system directs the power pump to develop, and by the actual resistance offered by the load.

1.7 In a control system employing a servo pump, the variations in gain resulting from a change of load are negligible as compared to those which may exist in the same circuit if control is exercised by a valve metering directly in the main power line.

2.1 In the servo valve field, Vickers has long experience with the design and incorporation of electrical torque motor controlled valves for the stroking of servo pumps.

2.2 To date, Vickers has designed and produced electro-hydraulic servo valves as an entity in themselves only for special, custom-made jobs. With its diversified line of hydraulic products suitable for servo circuit components, Vickers is in excellent position to take servo package responsibility for servo valves either of its own design or of such design as a customer may desire to specify. Vickers can then package this valve with a Vickers hydraulic motor (or a linear actuator), and filters, limit-stops, mechanical by-pass arrangements, relief valves, fail-safe looking device, special mounting provisions, etc.

2.3 The servo valve type of unit finds its application particularly in those fields where: (a) the highest response obtainable is desired for the application; (b) where there are a number of loads to be independently controlled, all in the same general location, so that a single hydraulic power source is more practical than an independent source for each load; and (c) where a hydraulic power supply is already available "for free," so to speak, as a part of some larger system. In these cases, the servo metering valves, packaged with auxiliary control items, may be conveniently placed in the lines emanating directly from the hydraulic source.

By emphasis on close technical liaison with the over-all system designer, Vickers guarantees the servo system performance of either a servo pump or servo valve package, and produces and tests the package to meet specific servo system requirements.

Sample performance curves of servo pumps and hydraulic units are shown in Figs. 1 and 2, respectively.

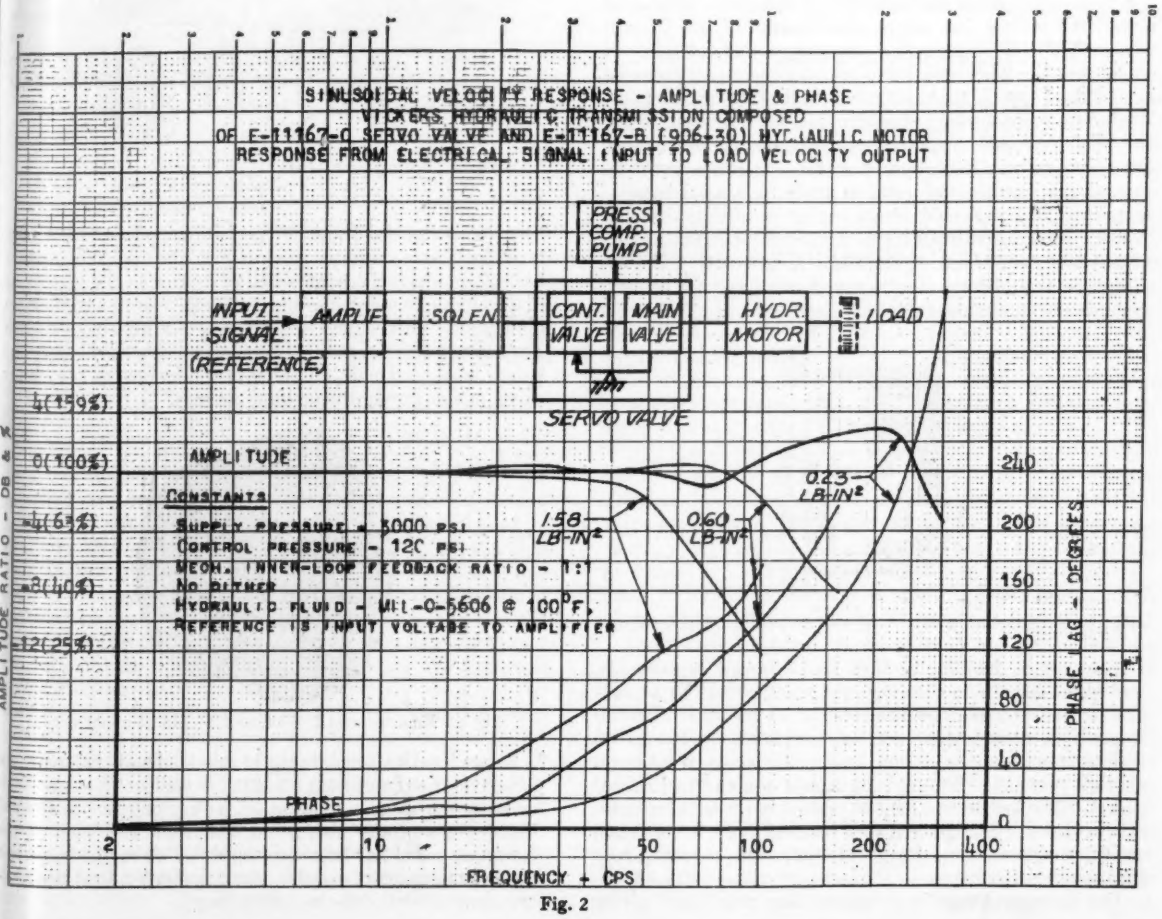



Fig. 2

# Ruggedized Instruments

**E. G. DeMOTT, Chief, D-C Development Division**

**Weston Electrical Instrument Corporation, Newark 5, N. J.**

A Subsidiary of Daystrom, Incorporated

ELECTRICAL indicating instruments are one of the important building blocks of the control and checking equipment associated with jet propulsion. Here the invisible electrical quantities derived from transducers actuated by the many functional elements are converted into visible indication so that they may be monitored or studied. As the final link in this chain of conveyance of intelligence, electrical indicating instruments must perform their designated functions both reliably, and adequately.

**Fig. 1 Head-on view of the $3^1/_2$-in. d-c instrument**

Weston Ruggedized Instruments are eminently suitable to serve the exacting and severe requirements of the jet propulsion field. By design they are rugged and reliable, yet do not lack the other desirable attributes commonly obtained in standard panel type electrical indicating instruments. Weston presents the only complete line of ruggedized instruments of four basic types; permanent-magnet moving-coil for direct current indication, movable iron for alternating current, and thermo and rectifier types for special applications involving extended frequency or sensitivity requirements. Ruggedized instruments are available in the $1^1/_2$ in. square style and $2^1/_2$ in., $3^1/_2$ in. and $4^1/_2$ in. round style cases to suit the requirement of economy of panel space at one extreme and maximum readability at the other.

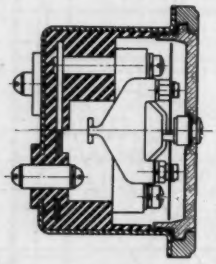


**Fig. 2 Sectional view of $2^1/_2$-in. and $3^1/_2$-in. d-c instruments**

Instruments, fulfilling as they do important functions in control, testing and monitoring equipment, should be as completely free of environmental effects as possible. Weston Ruggedized Instruments are so completely sealed as to withstand a four hour vacuum test at 2.5 inches of mercury, absolute pressure. Sealing is by means of a confined rubber gasket. The instrument may be opened in the field for emergency repairs or changes and then restored fully to its sealed condition without special tools or equipment, requiring only the use of a screwdriver.

The instrument case is of heavier than usual steel, giving both great strength and excellent shielding from external magnetic fields. The window is made of a tough heat-resistant plastic, enabling it to withstand, repeatedly, a standard drop test wherein a free-falling one-quarter pound steel cylinder is dropped on the center of the window from a height of eight inches. The plastic window also permits the incorporation of a self-sealed zero corrector, requiring only the use of a screwdriver from the front of the instrument for operations. The necessity of a zero corrector is well established; an instrument is no more accurate than the ability with which it can be set to zero.

The ruggedness of these Weston instruments results from careful attention to two aspects of design. First, the entire mechanism of the instrument is fastened to a shock mount integrally molded in and bonded to the heavy metal case. Second, the mechanism proper was designed specifically to be highly resistant to shock in its own right. The moving element rotates on specially developed rustless pivots working in spring-backed jewels. These jewels protect the pivot

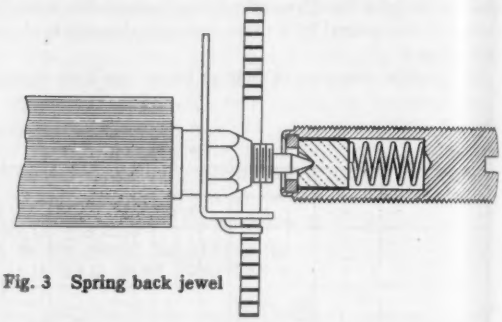


**Fig. 3 Spring back jewel**

tip under severe shock and also permit jewel clearance settings to be kept at a desirable minimum. The Alnico V magnet has soft iron pole pieces attached to it prior to the machining of the airgap, thereby affording excellent consistency of airgap dimensions. Beryllium Copper Springs are used in all Weston Ruggedized Instruments. Instrument connection studs are sturdy brass terminals imbedded in and bonded to the rubber shock mount during the molding process.

**Fig. 4 Rear view of $2^1/_2$-in. and $3^1/_2$-in. d-c instrument**

Ruggedized instruments can be provided with dial markings of luminous or fluorescent material, as well as the usual black or white markings. In addition, a very effective method of illumination of the instrument dial from the back of the mounting panel has been developed. This method provides good illumination of the dial markings with no extra projection on the front of the mounting panel.

# The Induction Modulator

**A. BROMLEY MULLER and GERALD STOLAR, Senior Engineers**

**Aircraft Navigation Department**

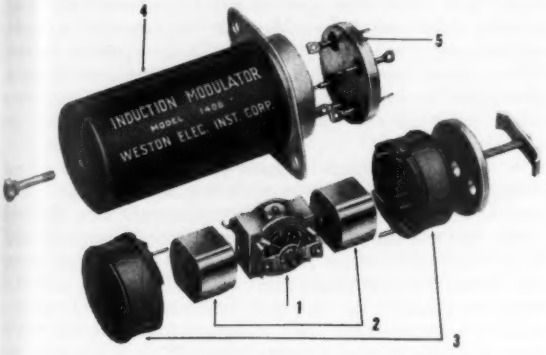
**Weston Electrical Instrument Corporation, Newark, 5, N. J.**

A Subsidiary of Daystrom, Incorporated

## General

THE continuous growth of the electronic age today is manifested by the introduction of new components and devices which may be suitably packaged to form the systems of tomorrow. One such new device is the Model 1408 Induction Modulator manufactured by the Weston Electrical Instrument Corporation, Newark, N. J. This device has been designed for those applications requiring the conversion of direct current to alternating voltage; and in comparison to existing transducers, such as vibrators or choppers, an entirely different type of operation is used.

The detail construction of the unit is shown in Fig. 1.




1. Mechanism Assembly
2. Permanent Magnets
3. Field Coil
4. Iron Case
5. Header

## Operation

The mechanism assembly consists basically of pole pieces, a frameless movable coil supported on a pivot and jewel structure, and the control springs. This assembly together with the permanent magnets, which are oriented axially, and the iron case, form the essential elements of a conventional D'Arsonval type d-c mechanism. Positioning of the movable coil is obtained in the usual manner by application of a direct current to its terminals. The field coils are mounted directly on the magnets and are connected electrically in series to produce additive fluxes with application of a-c excitation. The alternating flux set up by the field coils is axial in direction and will induce into the movable coil a proportionate voltage whose magnitude is a function of coil position and the electromagnetic characteristics of the system. Since the direct flux produced by the permanent magnets and the alternating flux produced by the field coils follow the same path, it was necessary in the design of the unit to limit the a-c ampere turns to a sufficiently small value so as not to noticeably demagnetize the magnet.

When the movable coil is positioned so that the plane of its turns is parallel to the alternating flux lines, there is no flux linkage and thus no induced voltage. This orientation of the movable coil is termed its zero center position, and the mechanical construction of the pole piece assembly will allow a rotation of as much as 50 degrees both clockwise and counterclockwise. The direction of the deflection is determined by the polarity of the applied direct current. For a fixed a-c excitation, the magnitude of the voltage induced in the movable coil will be substantially linear over the deflection range with respect to the applied d-c signal. Since opposite excursion of the movable coil from its zero center position reverses the coupling of its turns to the alternating flux, a corresponding 180° phase reversal occurs in the phase angle of the induced voltage with respect to the excitation. With a sinusoidal alternating voltage applied across the field coils the wave shape of the output voltage induced in the movable coil will also be sinusoidal with a very low distortion content. The design has been directed toward operation at a frequency of 400 cps, although the unit will function satisfactorily over the frequency range of 60 to 1000 cps.

When the unit is operated as explained above, it may be termed a modulator, and in contrast to other conversion devices it has conversion gain. When this gain is expressed as the DB ratio of the maximum a-c power output to the d-c power supplied, its value will be in the order of 28 DB. The unit may also be operated as a function multiplier, as it will resolve an a-c excitation applied to the field coils and the d-c signal applied to the movable coil into a voltage product.

## Design Considerations

The magnitude of the a-c output voltage obtained from the Induction Modulator is naturally dependent on the turns ratio of the field coil to the movable coil. Variations in either or both of these elements make possible a relatively wide selection of values which may be chosen to most advantageously match the signal requirements of the external circuitry.

In the initial development of the device, field coils were selected which would receive their excitation directly from the 115 volt 400 cps source so prevalent in aircraft applications. In order to obtain as large an output voltage as possible without overtaxing the heat dissipating capabilities of the construction, winding characteristics were designed to limit the excitation to a value of 1.25 watts. This results in a temperature rise within the unit of approximately 15°C when operated under standard temperature conditions.

It is interesting to note that where it is necessary to make use of excitation voltages lower than 115 volts, i.e., ranging down to 26 volts, coil windings may be chosen so that the magnitude of the output voltage will be unaffected as long as the input is limited to 1.25 watts excitation and the amount of copper in the field coils is kept constant. The impedance of the 115 volt design is 6150 $+j$ 5850 ohms and that of the 26 volt design is 314 $+j$ 300 ohms.

The number of turns on the movable coil has a dual significance in the operation of the Induction Modulator. As the number of turns is increased, the amount of current required for a fixed angular deflection is decreased proportionately, and at the same time the output voltage is increased proportionately. Naturally, there are definite design limits as to the maximum and minimum number of turns that can be wound, and this will establish a resultant range for the level of the d-c signal and the magnitude of the output voltage. Since it is thought that this device would be used in circuit applications where the level of the d-c signal is relatively low, the springs employed in the movable coil system

are kept to a practical minimum resulting in designs of maximum d-c sensitivity. The most sensitive d-c design would be 30–0–30 microamperes resulting in a maximum open circuit output of 1.9 volts 400 cps with a field coil excitation of 115 volts 400 cps.

## Linearity

Of particular importance in the Induction Modulator is the relationship between the d-c signal and the output alternating voltage. The deflection of the movable coil is determined by the strength and distribution of the magnetic field in addition to the other factors previously mentioned. The pole piece and core structure has been designed so that the permanent field will be essentially uniform in the air gap throughout the range of deflection of the movable coil. For that reason the deflection angle will be directly proportional to the d-c signal applied to the movable coil. This relationship will be linear to within 1 per cent of the full scale deflection of 100 degrees employed in the device. Since the alternating flux produced by the field coils acts to modulate the direct flux, it will follow the same path as the latter and its distribution over the deflection range will also be linear to within 1 per cent of full scale deflection. The input current to output voltage relationship will be the sum of the separate effects resulting in a linearity within 2 per cent of full scale deflection. In addition, skin effect on the alternating flux and pickup from leakage flux will result in a slight decrease in the linearity of operation so that the composite value of linearity will be within $2^1/_2$ per cent of full scale deflection. Where applications require better linearity of operation, the deflection angle may be restricted to 40–0–40 degrees resulting in the linearity within $1^1/_2$ per cent of full scale deflection.

## Damping

The movable coil in the Induction Modulator is frameless in construction, as a frame would present a shorted turn to the alternating field. Therefore, the device has no inherent damping other than the relatively negligible amount produced by the air media itself. When a fixed response time for a certain percentage of deflection of the movable coil is required for a specific application, the necessary damping to accomplish this must be supplied by external circuitry connected to the moveable coil; e.g., a shunt resistor. However, this element would act as a direct load to the induced voltage thus reducing the terminal voltage available to the output circuit. Therefore, the external circuit design must take into account not only the response requirements for operation of the d-c mechanism but also the power output requirements. To maintain better flexibility in design for both requirements it would naturally be best to isolate the output from the d-c signal circuit.

Basically then, because of this lack of any inherent damping, the Induction Modulator is a highly underdamped device, having an undamped natural period of about 0.37 sec for the most sensitive d-c design. However, proper selection of the external circuit resistance will enable the designer to obtain a wide range of selectivity for the response requirements, with a consequent sacrifice in the d-c power level of operation. For example, a shunt resistance of about five times the value of the movable coil will produce critical damping of the d-c mechanism. This will result in a response time of about 0.12 sec for 62.8 per cent of full scale deflection. A decrease in the shunt resistance to about one fourth that of the movable coil will produce an overdamped condition having a specific damping coefficient of about 3.9 and an associated response time of 0.50 sec for 62.8 per cent of full scale deflection. Where much slower response than this is required, it would be best to utilize time delay circuits for impressing the d-c signal.

## Phase Shift

In certain applications of the Induction Modulator it is desirable to have a known phase relationship between the input voltage applied to the field coils and the output voltage induced in the movable coil. The phase angle of the current flowing through the field coils with respect to the applied voltage is approximately 45° lag and is determined by the impedance characteristic of the circuit. Theoretically the voltage induced in the movable coil should lead the field current by 90 degrees and consequently lead the input voltage by 45 degrees. In practice, however, this ideal quadrature condition is not obtained due to hysteresis and eddy current effects throughout the iron path, causing the output voltage to lead the input voltage by approximately 22 degrees.

Should an application require a phase relationship to exist other than that mentioned above, this may be accomplished by means of external circuitry. One such circuit that has been tried successfully consists of a shunt capacitor connected across the field coils, the combination being excited through a series resistor. This circuit serves to shift the phase relationship of the field current with respect to the input voltage in such a manner that the output voltage and input voltage are brought into phase, providing the proper values of resistance and capacitance are employed. It should be noted that since this method requires a relatively large amount of shunting of the field coils by the capacitor, a considerable amount of power will be lost in the external resistor. Where power consumption is an important consideration, this phase correction can, if desired, be made at some other point in the circuit following the output of the modulator.

A correction can also be made to provide for the output voltage to be in quadrature with the input voltage. This may be accomplished by using a series capacitor to shift the power factor angle of the field circuit from its normal value of 45° lag to 23° lead. This method will result in no power loss external to the modulator. Both this circuit and that mentioned above for in-phase operation, will require a modulator with field coils designed for operation lower than 115 volts in order to provide for 1.25 watt input to the modulator.

As previously mentioned, the relative phase shift of input voltage to output voltage is affected by eddy current losses within the modulator. Experiments have been conducted using parts made from special high resistivity alloys and a marked reduction in eddy current loss has been affected. This resulted in the output voltage leading the field current by 80 degrees instead of the 67 degrees obtained with iron. An increase in output voltage of approximately 10 per cent also resulted. However, since fabrication of parts using high resistivity alloys is extremely difficult from a machinability viewpoint, this type of construction should only be used for the rare applications where it is absolutely necessary.

## Balance

Since the mass distribution of the movable system is not symmetrical about the pivot axis, it is necessary to provide a means for statically balancing the system; otherwise, the position in which the modulator is operated would affect the output voltage. This has been accomplished by means of the balance cross and movable weight system common to instrument design. Since it is impossible to obtain an absolutely perfect balance and also because some looseness between the pivots and jewels is necessary to prevent friction, there will be a slight change in output voltage as the modulator is rotated into various positions. This position error is held within ±1 per cent of the end scale output voltage. Where it is desired to minimize this error, the modulator, if possible, should be mounted with the pivots in a vertical position.

### Performance

As can be seen from viewing Fig. 1, the entire construction of the Induction Modulator is quite compact, being approximately 2.4 inches long, 1.1 inches in diameter, and weighing 5 ounces. The mechanical construction is designed to be rugged enough to assure adequate performance under the usual environmental conditions imposed on airborne devices. The unit in addition is hermetically sealed in construction thus making it impervious to such exposures as salt spray, humidity and sand and dust. In contrast to a conventional d-c instrument, the movable coil system is relatively light because the movable coil, itself, is frameless in construction and the pointer is only made large enough to provide contact against the pointer stops to prevent travel beyond end scale deflection. This results in reduced wear of pivots and jewels.

In closing it is worth noting that conversion devices, such as vibrators and choppers, in use prior to the introduction of the Induction Modulator, operate on a principle of making and breaking of contacts. It is a recognized fact that there is some deterioration in contact surfaces with operation, resulting in an unpredictable life expectancy for such devices. The principle of operation of the Induction Modulator naturally eliminates this disadvantage. Furthermore in contrast to other types of conversion devices the Induction Modulator will present a constant resistance to the d-c signal input and will also be unaffected by pickup from stray fields.

# Tachometers for the Measurement of High Speeds

**A. H. WOLFERZ, Chief, A-C Development Division**

**Weston Electrical Instrument Corporation, Newark 5, N. J.**

A Subsidiary of Daystrom, Incorporated

THE measurement of high speed, in excess of 10,000 rpm, presents many problems such as bearing design, elimination of sliding contacts or reciprocating parts, the requirement of low inertia, and a minimum of torque burden.

A most convenient and proved method is to attach, to the shaft to be measured, a small cylindrical magnet of a size suitable for the speed to be measured; see Fig. 1. This magnet is allowed to revolve between the poles of an electrical pickup. This pickup is termed a stator and may take on many forms to suit the application; one form is shown in Fig. 1. The rotor and stator shown in Fig. 1 are suitable for speeds up to 15,000 rpm. Above this speed these elements would become smaller and have either 4 or 2 poles according to the speed. The two pole type would be suitable for speeds of 50,000 to 100,000 rpm. The rotor in this case would be not over 0.5 in. in diameter and 0.5 in. long. Such a rotor would have a weight of approximately 5.6 grams and a moment of inertia of 1.15 gm. cm.$^2$.

Such transducers produce alternating voltage and frequency, which are proportional to the speed, for the operation of the indicating, controlling, and recording element termed receiver.

The simplest and least expensive receiving elements are those which are responsive to the voltage. These can be voltmeters, millivoltmeters, relays and recorders. However, in such transducers the voltage, while being proportional to speed, is also influenced by the resistance of the circuit and the permanence of a permanent magnet.

The voltage developed by the transducer is also influenced by the position of the rotating element in the stationary element. It is this latter characteristic which requires the final adjustment to be made after installation. The indications for this type may be relied upon to ±2.5 per cent of top speed or better depending on the instrument.

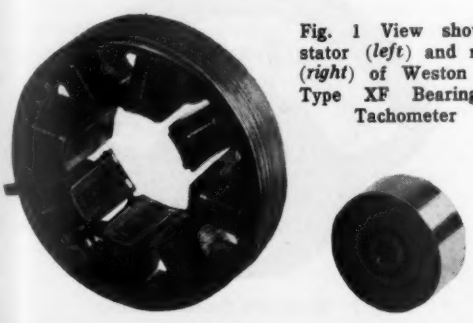


**Fig. 1 View showing stator (*left*) and rotor (*right*) of Weston 758 Type XF Bearingless Tachometer**

The transducer may take on various forms as shown in Fig. 2 and Fig. 3.

When high speeds are to be measured the transducer may be reduced in size and may be contained within the device of which the measurements are to be made. These may take forms as shown in Fig. 4. Unless mechanically damaged these require no servicing.

### Frequency Responsive Tachometer Systems

The basic circuit is shown in Fig. 5. It consists of four parts: (1) a-c generator, (2) saturable core transformer, (3) rectifier network, and (4) d-c indicator.

The generator has been briefly described in the preceding paragraphs. However, additional facts should be understood. The extension of the shaft of which the speed is to be measured may take on various designs. When the maximum speed encountered is 5000 rpm or above, this extension should be an integral part of the main shaft and carefully ground to centers. Likewise, the rotor must be accurately ground to centers. Cast Alnico II is not recommended for speeds beyond 25,000 rpm, in which case sintered Alnico will serve but must be spin tested to a safe margin above the highest speed to be encountered. Since the indications are a function of frequency and not voltage, the exact location of the stator with reference to the rotor is not important. So long as the stator does not touch the rotor and the rotor does not project beyond the stator more than 1/4 in., the results will not be affected. Rotor magnets are brazed or sintered to a mounting bushing, charged magnetically with the proper number of poles, and stabilized at the desired strength.

**Fig. 2 Exploded view of ring and sleeve mounting for Weston Model 758 Type HF Bearingless Tachometer**

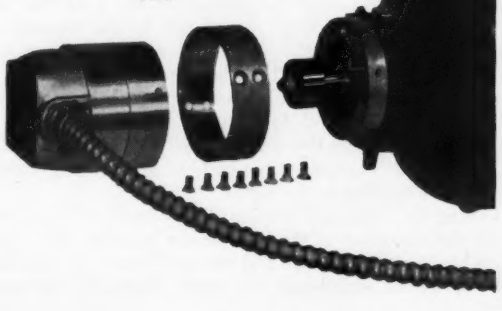


Fig. 3 Rotor and flange-mounted cast iron case for stator—Weston Model 758 Type GF

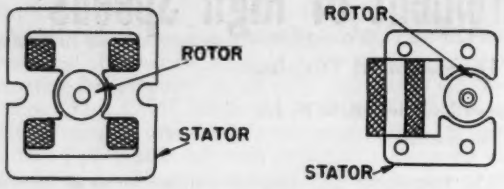



Fig. 4

2 Pole rotor and stator with 2 coils

2 Pole rotor and stator with 1 coil

They may be mounted or dismounted from the shaft without change of instrument adjustment or calibration.

The Fig. 6 table has been established as a basic rule of thumb for the number of poles and coils:

The transformer is of the closed ring, ribbon wound, core-type with toroidal windings for primary and secondary. The core is of such material that it will saturate with as little as 0.3 oersted and, when saturated, the flux density is approximately 14,000 gausses.

The rectifier is of the full-wave type with the bridge completed by resistors so as to decrease the effect of temperature and also protect the rectifiers against the peak voltage from the transformer in event of an opening in the movable coil circuit of the indicator.

The indicator is a d-c instrument of the permanent-magnet movable-coil type having such current sensitivity and resistance as to properly match the rectifier circuit. The scale of the instrument is quite uniform, departing from linearity by about 1 per cent of the full scale length. See Fig. 7 (Model 273 Speed Indicator).

D-c Relays, such as shown in Fig. 8, may also be used where speeds are to be controlled.

The speed values may be recorded as well as indicated by means of recorders. See Fig. 9.

## Theory of Operations

The explanation of what takes place in the circuit is shown graphically in Fig. 10. (a) represents the generator emf, or no-load voltage. When connected to the transformer, the terminal voltage of the generator has a modified sine wave shape as shown in (b). The sharp peaked portion of the emf wave, extending for only a small part of the total wave, is that portion needed to saturate the transformer core. Graph (c) represents the core flux, and (d) shows the effect of the core flux changes on the emf in the secondary winding from one saturation to the next.

During the saturated portion, the secondary emf is zero. When the secondary of the transformer is loaded, the voltage wave broadens at the base and becomes shorter in amplitude (e). If loaded sufficiently, it would ultimately become a

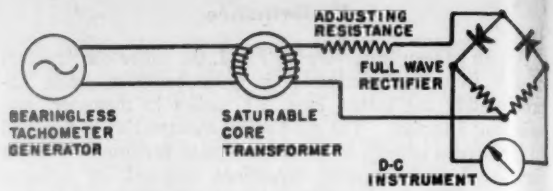



Fig. 5 Basic circuit for bearingless generator type tachometer

| *Speed* | *Rotor Poles* | *Stator Coils* | | *Frequency-CPS* |
|---|---|---|---|---|
| | | *No.* | *Res.-Ohms* | |
| up to −15,000 | 8 | 8 | 32 | up to −1,000 |
| 16,000 to 25,000 | 4 | 4 | 16 | 260 to 833.3 |
| 26,000 to 80,000 | 2 | 2 | 8 | 200 to 1,333.3 |

Fig. 6 Generator details

sine wave and the transformer would no longer be saturated. After rectification, the current applied to the indicating instrument is a d-c pulse as shown in (f). The actual current in the primary winding of the transformer, together with the current necessary to saturate the core, is shown in Fig. 11. This shows that the core is saturated at all speeds.

## Effect of Generator Voltage Changes

For any given speed, the effect of voltage change, due to drop in flux of the rotor or shift in alignment of rotor and stator, creates a very small effect as shown in Fig. 12. A drop of 20 per cent in generated voltage results in only a 1 per cent change in indication.

## Over-All Accuracy

The over-all effect of ambient temperature is within 1 per cent for any temperature from −40 to 40 degrees Centigrade.

The difference between the accuracy of this frequency responsive system and that of a voltage responsive system is the result of the elimination of the variance allowed for the generator. This results in an over-all accuracy of approximately $\pm 1^1/_2$ per cent of full scale value when used with a panel or switchboard type of instrument.

Adjustment of the system is made by means of the series resistance between the secondary of the transformer and the rectifier. Its value is dependent on the secondary burden current required. This current is proportional to the secondary turns and frequency, and since the turns are fixed, the current is therefore proportional to frequency.

Fig. 7 Model 273 Speed Indicator

Fig. 8

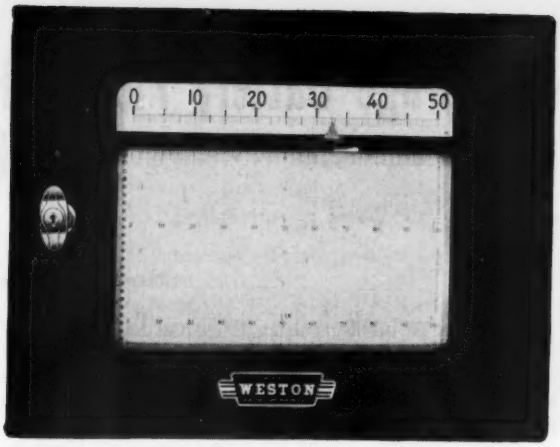



Fig. 9

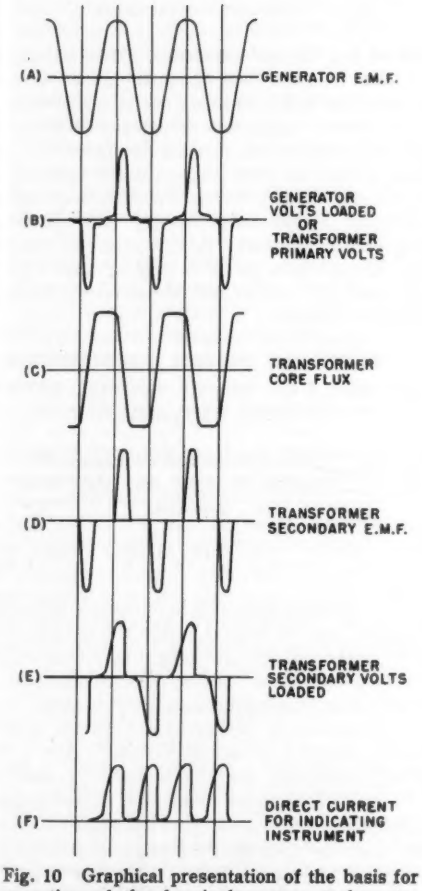



Fig. 10 Graphical presentation of the basis for operation of the bearingless type tachometer

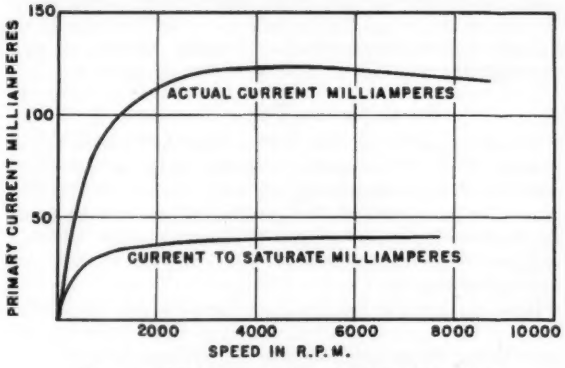



Fig. 11 Graphic illustration showing the ability for retaining saturation in transformer core

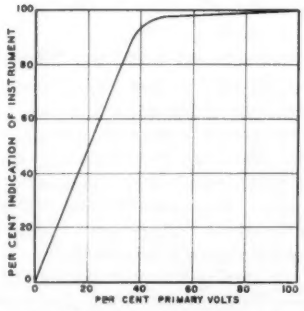



Fig. 12 Graphic illustration of generator voltage effect

# Storage Battery Picture Has Silver Lining in Missiles and Rockets

MICHEL N. YARDNEY

**President, Yardney Electric Corporation**

OF the varied problems facing design and development engineers in the missile field none, perhaps, has been more difficult to solve than that of finding a more adequate, dependable source of battery power than has been available in aeronautics to date.

The complexities of weight, space, and severe current drains —always critical in the aircraft field—have, because of ever-increasing electronic and electrical systems loads, advanced to the point of no return for the missile designer. Yet, while working in a field where military requirements have forced a continual advance in both miniaturization and performance of components, he has had to face up to the fact that, until recently, the batteries he needed to supply electrical energy were virtually the same as in horse and buggy days.

### Breaking the Power Barrier

It is little wonder in view of the above that the advent of Yardney Silvercel* storage batteries produced great immediate interest within the engineering fraternity—or that within a few years they have come to be depended on in a wide range of applications involving advanced, secret missiles, aircraft, torpedos, radio communications, television, and motion picture equipment.

Here, at last, is stored electrical energy which, because of compact high-capacity, constant voltage characteristics, appeals to the design engineer who must escape limitations of heavy, bulky, ordinary batteries.

Here is a power source that permits the development engineer to use his imagination with future designs—with the full knowledge that Yardney Electric Corp. scientists, now designing batteries in capacities ranging up to several thousand ampere-hours, will meet every requirement—be it strategic or design.

### Development of Yardney Silvercel*

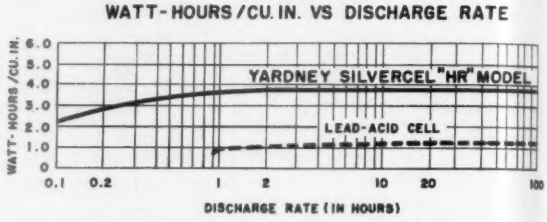
Although revolutionary in that it is history's first rechargeable storage battery to utilize silver and zinc, the Silvercel is a practical, proven source of electrical energy.

Early experiments—even in Volta's day—showed conclusively that this electrochemical system is far superior to that of any other couple. It is perfectly reversible and capable of supplying at a constant voltage more electricity than any other battery of the same size and weight.

But it was only during the past decade that the the research of our New York and associated laboratories developed further the initial discoveries of the eminent French scientist, Prof. Henri Andre, into an electrochemical couple practical for a wide variety of rechargeable storage batteries. These developments have since become known internationally as the Andre-Yardney System.

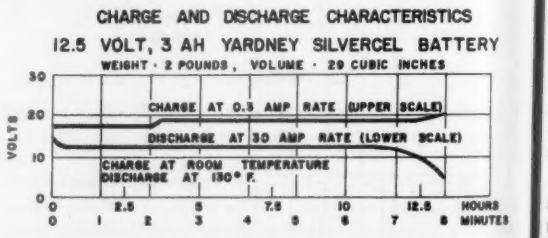
### Superior Characteristics

● Silvercels, on the average, are six times lighter, five times smaller and capable of supplying much greater current—or, to put it another way, they provide four to five times as much energy as any other battery of the same size and weight. (See curve.)




● Because of low internal resistance, Silvercels can be discharged at rates 20 times their numerical ampere-hour capacity, thus providing, unlike ordinary batteries, extremely great amounts of power to meet any emergency or to compactly serve high drain applications of short duration.

● Supplied voltage of these high-capacity batteries is virtually flat throughout the discharge period, thus insuring the highest possible operational efficiency and dependability. Depending on the discharge rate, voltage of the average secondary Silvercel (one cell) will vary between 1.5 volts at light drains and 1.0 volt at loads designed to discharge the unit within two minutes.



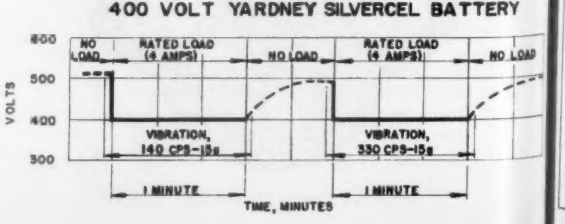

● Requiring minimum attention in operation, Silvercels, like any component, can be housed within the package they are designed to power without providing a maintenance problem

Other key advantages of Yardney Silvercels include:

● Extremely wide temperature and pressure range operation. They afford dependable performance between −60°F and 160°F and at altitudes as high as 85 miles. Also a "built-in self-heating" capability permits a battery, stabilized at −65°F, to be warmed up and made operational within a few minutes through the simple expedient of short-circuiting.

● Rugged construction features that make possible dependable performance while withstanding severe acceleration, vibration, and shock loads as high as 1000 G's. (Note curves.)

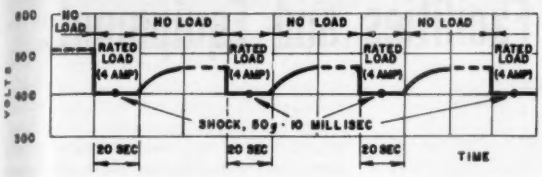
● Spillproof construction and practically gas-free operation.




* Reg. U.S. Pat. Off.
World-wide Patents Granted and Pending

SHOCK TEST

400 VOLT YARDNEY SILVERCEL BATTERY




• Primary and secondary formulations, each lending itself readily to series and parallel operation. Secondaries can be charged at high rates and provide ampere charge efficiency close to 100 per cent under most operating conditions.

## Power for Every Purpose

With strategic as well as engineering design problems in mind, Yardney Electric Corporation engineers have developed Silvercels in three series and several types of primaries and secondaries. As a result, these advanced silver-zinc batteries, even in standard production models, more nearly approach individual engineering needs than any other battery.

Also, because of the combined effort of our scientists and engineers, it is possible to design and develop rapidly Silvercels of unusual configuration and capacity to solve unique design problems. (Note: A good example of this engineering proficiency was pointed up recently when, in answer to a military request, a completely new battery was developed, designed, and evaluated successfully within eight weeks.)

Silvercel batteries have been developed as:

• **Standard Secondaries,** which can be stored in a wet, charged condition for more than one year with a capacity loss under controlled storage conditions not exceeding 20 per cent.

• **Dry-Charged Secondaries,** with a storage of years, which are operational within hours after electrolyte is added.

• **Specially-Prepared Secondaries,** developed to meet requirements for extreme, long-term storage of batteries in a wet, charged condition.

• **Automatic Primaries,** affording almost unlimited shelf life, which are operational instantaneously in any position.

• **Manually-Activated Primaries,** with unlimited shelf life, which are ready for use within minutes through the simple expedient of adding electrolyte.

Standard production models range from postage-stamp size Silvercels as small as $^1/_{10}$ ampere-hour to high-capacity units of 300 ampere-hours. Silvercels in capacities of several thousand ampere-hours also have been designed and currently are under extensive laboratory evaluation. A representative list of production models in the high rate series follows:

**Table of Yardney High-Rate Models**

| Yardney Silvercel® | Nominal capacity | Peak pulse discharge (amp) | Weight (oz) | Height (all in inches) | Width | Depth |
|---|---|---|---|---|---|---|
| HR 01 | 0.1 AH | 3 | 0.14 | 1.38 | 0.61 | 0.20 |
| HR 05 | 0.5 AH | 30 | 0.72 | 1.52 | 1.10 | 0.55 |
| HR 1 | 1.0 AH | 45 | 1.00 | 1.98 | 1.08 | 0.54 |
| HR 3 | 3.0 AH | 75 | 3.00 | 2.86 | 1.72 | 0.59 |
| HR 5 | 5.0 AH | 75 | 4.13 | 2.95 | 2.08 | 0.80 |
| HR 10 | 10 AH | 220 | 7.50 | 4.78 | 2.32 | 0.74 |
| HR 20 | 20 AH | 500 | 13.60 | 4.28 | 2.05 | 1.73 |
| HR 21 | 20 AH | 500 | 15.0 | 7.56 | 2.31 | 0.81 |
| HR 40 | 40 AH | 600 | 23.0 | 7.0 | 3.25 | 0.99 |
| HR 60 | 60 AH | 1000 | 32.1 | 4.50 | 2.75 | 2.38 |
| *HR 85 | 100 AH | 1900 | 53.0 | 9.44 | 2.81 | 1.81 |
| HR 90 | 100 AH | 1800 | 53.0 | 7.0 | 3.25 | 2.16 |
| HR 100 | 100 AH | 2000 | 43.5 | 4.78 | 3.43 | 2.79 |

* Used in only airborne storage battery able to repeatedly start a jet engine.

HR Series models are suitable for applications where extreme, high discharge currents are necessary.

HRV Series models are designed for longer life (up to 75 cycles) while providing discharge currents approaching the highs of the HR series.

LR Series models provide extreme, long life (up to 400 cycles) at current drains lower than a one-hour rate.

## Application in Missiles

Realizing the potentiality of rechargeable silver-zinc batteries, missile engineers have taken advantage of the superior characteristics of Silvercels. Why? Because a secondary battery provides an engineer with a multi-lived power source for exhaustive laboratory, wind tunnel, and flight tests. Also, a secondary furnishes a degree of dependability not yet found in the primary field.

Thus our Silvercel batteries are relied on heavily for powering telemetering equipment, instrument packages, servo units, and flight-battery units.

Military security prevents a detailed discussion of present applications in the missile field, but let's look at a telemetering package that would require Silvercel power because no other rechargeable battery could meet the specifications.

The requirements call for a battery to provide simultaneously as many as eight different voltages in a range from −100 volts to several hundred volts positive and to deliver power in excess of 500 watts. Yet the unit must not exceed a volume of 250 cubic inches and weigh only about 40 to 50 pounds.

Specifications require further that the battery be capable of performance at temperatures between −65°F to 125°F at relative humidities up to 100 per cent and under a pressure range from near-zero to 30 inches of mercury.

Specifications also call for the battery efficiency to be unaffected by adverse atmospheric conditions such as snow, hail, ice, fog, smoke, wind, and salt. Acceleration, vibration and shock requirements are that the unit withstand an instantaneous load of 50 G's.

Additional requirements prescribe that variation in output voltage at the prescribed load currents be extremely small, that internal impedance be approximately 0.001 ohm. Explosion proofing and low noise levels also are requested.

Our Silvercel is the only secondary battery capable of solving the problem.

The number of power packages installed in a given missile, naturally, are governed by specific needs. Silvercels often are required for a heavy-duty battery to power servos and other electrical or electrically-actuated hydraulic systems. A heavy duty secondary battery of 28 volts, utilizing Silvercels of 100 AH capacity, is capable of delivering 300 amperes for more than 10 minutes. Yet it has a displacement of less than 1600 cubic inches and weighs only about 85 pounds.

Indicative of the capacity attainable in high-voltage applications is a Silvercel unit comprising 320 1 AH cells which delivers up to 400 volts at rated loads. This battery requires a volume of only 700 cubic inches and weighs less than 40 pounds.

Although a missile is considered a short-life, expendable item, it is common to have power packages designed for a continuous operating life of 300 hours, and able to withstand frequent on-off switching over prolonged time periods.

## Tests Point to Future

Elaborate acceptance tests, established to test compliance with stringent requirements in the missile field, prove that Yardney Silvercel batteries are extremely suitable for all types of present-day applications. In addition, these specially devised test procedures, coupled with extensive research now being conducted by our engineering department, promise battery power progress in keeping with the advances anticipated in the missile and rocket fields in the foreseeable future.

# Low and High Temperature Facilities and Equipment

THE main plant of Herrick L. Johnston, Inc., is located in Columbus, Ohio, and consists of 55,000 square feet of well-equipped shop and office space.

Sixteen acres of land have also been acquired in Los Angeles, Calif., for contemplated expansion and for development of a West Coast branch. Approximately 4000 square feet of engineering office spaces are immediately available on this property and shop facilities will be constructed when the time appears suitable.

Especially unique facilities for research and development include cryogenic facilities and high temperature research facilities built around high frequency induction heating.

The Herrick L. Johnston organization has attained a name for work of the *highest quality* in research, in design, in engineering, and in fabrication. It has attained an enviable reputation for accepting difficult assignments and doing them well, and for prompt performance on very tight time schedules.

All personnel are unusually versatile in skills and are experienced in making rapid adjustments to the requirements of new assignments.

The nucleus of the Herrick L. Johnston organization consists of scientists and engineers who were associated with Dr. Johnston in The Ohio State University Cryogenic Laboratory and in his proprietorship contracts. It now includes on its staff eminent physicists, chemists, and chemical, metallurgical, mechanical, electrical, instrumentation, industrial, and design engineers, as well as draftsmen, administrators, and management specialists.

The experience of the organization and of the group of personnel encompasses a broad background: both low and high temperatures, high pressures, high vacuum, special apparatus and instrumentation, chemical and physical thermodynamics, physical and engineering properties of materials, heat transfer, gas properties and technology, properties of metals, and chemical reaction kinetics, adsorption and catalysis, stress and strain analysis, and vibrational analysis.

Dr. Herrick L. Johnston was Professor of Physical Chemistry in The Ohio State University from 1929 to 1954. He established and directed the world-famous Ohio State University Cryogenic Laboratory and The Ohio State University Rocket Motor Laboratory.

Being an author of more than 150 scientific and technical papers and books, Dr. Johnston has covered research in low temperatures, liquefied gases, thermodynamics, gas properties, atomic and molecular structure and spectra, high-temperature chemistry, and physical metallurgy.

He has served as a consultant on research and development programs for the Aerojet Corporation, the Linde Air Products Company, the National Bureau of Standards, The Glenn L. Martin Company, the Curtiss-Wright Corporation, Battelle Memorial Institute, Los Alamos Scientific Laboratory, G. M. Giannini and Company, Hydrocarbon Research, the University of California Radiation Laboratory, the United States Atomic Energy Commission, and others.

Having made several extensive technical missions to university, industrial, and government laboratories throughout western Europe, Dr. Johnston is well acquainted with leading European laboratories, their programs, and their personnel.

Dr. Johnston received a "starred" rating in *American Men of Science* in 1938, which placed him among the thousand leading American scientists. (Further details of his experience and background are contained in both *American Men of Science* and *Who's Who in America*.)

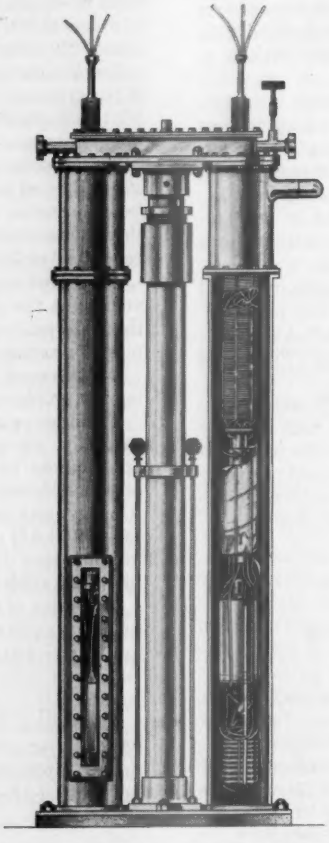


**Fig. 1 Herrick L. Johnston hydrogen liquefier**

Special features insure low heat leak. Extended research and development experience of the Herrick L. Johnston organization in cryogenic fields has resulted in reducing the heat leak into the V 28,000 LOX vessel to less than 6000 watts, which corresponds to a 24-hr evaporation loss of less than 0.15 of one per cent of the rated liquid capacity.

The Ohio State University Cryogenic Laboratory, founded by Dr. Johnston in 1941, developed within eight years into one of the principal low-temperature research laboratories in the world. Its numerous research contracts dealing with all phases of low-temperature research, high-pressure research, gas properties research and technology, chemical and engineering thermodynamics, material properties at both high and low temperatures, isotope identification and separation, design of apparatus and instrumentation have been principally in the interest of national defense—ONR, NACA, AEC, NECA, NEPA, etc. Among its principal programs have been development of rocket motors using liquid hydrogen as fuel, various thermodynamic programs for the Office of Naval Research, and highly classified research and development in the atomic energy program. Much of its work, for security reasons, has not been generally known; but its research and technical publications on unclassified material have earned world-wide recognition. The following is a partial list of products designed and manufactured to date:

*Stationary plants* for the production of liquid air, liquid oxygen, liquid nitrogen, liquid hydrogen, and liquid helium.

*A trailer-mounted mobile plant* for the production of liquid hydrogen.

*A trailer-mounted compressor.*

*Vessels* (various sizes up to 28,000 gallon capacity) for the ground storage of liquid oxygen and liquid nitrogen.

*Low boil-off rate*

4000 liter dewar—0.36% in 24 hr
6000 liter dewar—0.32% in 24 hr
8000 liter dewar—0.30% in 24 hr

*Vessels for the transport* of liquid hydrogen and liquid helium by air.

*Vessels for road transport* of liquid oxygen, liquid nitrogen, and liquid hydrogen.

*Vessels for the storage and transport* of liquid fluorine.

*Ground-handling equipment* for aircraft breathing oxygen.

*Liquid-to-gas converter* for aircraft breathing oxygen.

*Liquid pumps and vaporizers* for the conversion of liquid nitrogen and liquid oxygen to high-pressure gas.

*Transfer pumps and filters* for liquefied gases. Pumps: Design of liquid oxygen and nitrogen pumps, both centrifugal and reciprocating, with working pressures from 0 to 5000 lb. Flow rates for reciprocating pump from 5000 to 30,000 scfh.

*Filters:* All stainless steel construction and compatible with liquid oxygen, liquid nitrogen, and organic propellant fuels. Rated to remove all particle sizes greater than 12 microns. Design for convenient, easy removal of filter for cleaning and servicing.

*Transfer lines and quick disconnect couplings* for liquefied gases.

*Valves* for liquid oxygen, liquid nitrogen, and liquid hydrogen service.

*Liquid level gauges, thermocouples, and other instrumentation.*

Herrick L. Johnston, Inc., vacuum-jacketed storage and transport vessels are designed for minimum evaporation losses, low maintenance costs, and ease of operation. They are also equipped with modern instruments. The Bourdon tube-type gauges are employed to measure gas pressures within the vessels and to measure low vacuum in the vacuum spaces. High and moderate vacua are measured by molecular and thermocouple gauges. Also included for measuring of liquid level is a very sensitive differential pressure indicator selected for its sensitivity and ease of maintenance. A flowmeter is employed to measure any vapor loss that may occur through operation of the relief valve. Electrical equipment furnished with these dewars conforms with all applicable electrical codes stated in manual of the National Electrical Manufacturers' Association. All dewars have a built-in vacuum system containing a Kinney-type vacuum pump selected to meet the high requirements of performance expected of these storage vessels. This pump is capable of a dead-end pressure of better than 0.2 microns pressure absolute.

*A constant program of research and development is carried on by Johnston scientists and engineers, which continues a tradition of thirty years of research, by Herrick L. Johnston, in the field of liquefied gases.*

**Fig. 2 Mobile liquid hydrogen plant**

This mobile plant has a capacity of 100 liters of liquid normal hydrogen per hour, or 65 liters per hour of liquid para hydrogen. The water-cooled compressors are mounted in separate trailers.

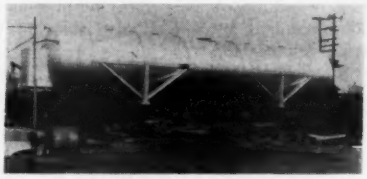


**Fig. 3 28,000-gal storage vessel for liquid oxygen or liquid nitrogen**

This vacuum-jacketed vessel, capable of storing 28,360 gallons of liquid oxygen, has been engineered to satisfy the anticipated needs of the customer. The inner tank, containing the liquefied gas, is suspended within the outer tank by a low-leak suspension system.

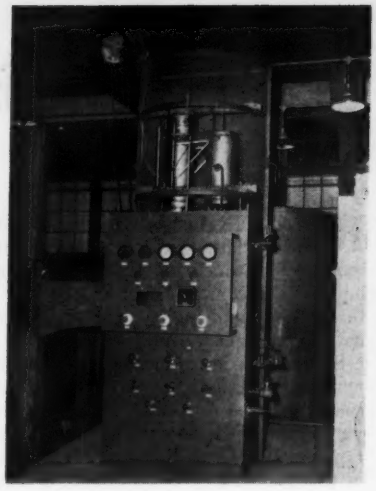


**Fig. 4 Liquid nitrogen rectification column**

A liquid nitrogen rectification column capable of producing 47.4 liters per hr from 65 liters of liquid air. The unit consists of a fractionating column, heat exchanger, nitrogen reservoir, and Joule-Thomson valve enclosed by a metal framing filled with a powdered insulation. The column valving consists of a liquid air expansion valve, liquid air reflex valve, and is manually controlled at the instrument panel.

## Giannini Datex Digital Data Recording Systems

(*Continued from page 16-S*)

The other equipment consists of: a regulator which permits the supply to vary between 105 and 130 volts and 55 and 65 cps; a chassis that provides d-c voltages for the System Control Chassis; a System Control Chassis that accepts synchronizing signals and the time code from the range time source. These signals are amplified and combined in such a way as to provide the proper timing signals for Channels "A" and "B." The System Control Chassis also contains the circuits necessary to accumulate the time code in serial and transfer this code in parallel to Channels "A" and "B."

## Temperature and Pressure Measurements

(*Continued from page 3-S*)

In-flight measurements of afterburner thrust can be obtained through the use of probe H-1048 for total pressure and T-1006A for total temperature when the temperatures are below 3000 F. Probe H-1048 can also be used for the sensing element of gross thrust meters or for pressure ratio or pressure difference indicators. When the temperatures of the afterburner are greater than 3000 F in flight, the swinging arm type of probe is used (cat. no. 1855). This consists of passing an uncooled pitot static probe and a total temperature probe through the hot gases at a rate sufficiently fast to prevent melting of the probes. The trajectory through the afterburner is an arc. This method has been successfully used to obtain thrust with accuracies of $\pm 2$ per cent of the true value, using our new high temperature material, permitting resident time in the afterburner.

Many of the above instruments were developed or made usable through the laboratories of Aero-Research. With our wind tunnel and calibrating facilities we are able to develop, build, and test sensing elements to meet your requirements.

## Photographic Data Recording and Instrumentation Systems

(*Continued from page 21-S*)

6 Portable Developing Apparatus, for rapid processing of 16, 35 and 70-mm films, on the ground, or airborne.

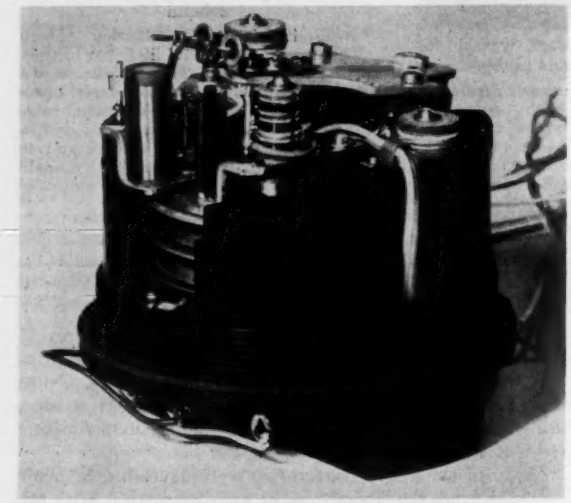
7 Projection, Viewing, and Analysis equipment, for photographic data reduction.

In addition, the company serves as distributor and applications consultant for a number of specialized recording cameras, infrared image converters, high-speed cameras and their accessories, which are employed in wind tunnel studies, schlieren photography, flame propagation studies, analysis of rapidly moving machinery, etc., which may prove valuable in the design and preliminary test stages of a project.

# Giannini Resistance-Type Pressure Transmitters

REFLECTING customer demand, the majority of Giannini Airborne Instruments incorporate precision potentiometers which provide an electrical output linear with input. The company has also become highly proficient in the art of supplying nonlinear outputs which conform to natural or empirical functions.

Shaped coil forms are generally employed to provide the nonlinear function. However, several alternate methods are successfully used. These include the process of adding a number of fixed resistors to the potentiometer element by tapping their leads directly onto the windings. A variation of this system is sometimes used whereby the tap leads are brought to terminals on the instrument case for external padding as required.



**Typical Giannini Pressure Transducer**

Potentiometer elements in Giannini instruments are wound with precious metal wires on carefully prepared ceramic or glass coil forms, by skilled operators using precision coil-winding equipment. To assure long noise-free life, low contact pressure precious metal brush wipers are also used. This combination of precious metals makes possible the low friction and high sensitivity that are characteristic of Giannini instruments.

The electrical elements for Giannini potentiometer output transducers can be connected either as a rheostat or as a potentiometer. Generally, the potentiometer arrangement has certain advantages over the rheostat type. For example, the effective output of a potentiometer is a voltage ratio, and this ratio is relatively independent of changes in resistance caused by changes in temperature, thus permitting the use of precious metals for wire and brush materials. Likewise it is relatively unaffected by reasonable changes in the applied voltage.

***Bourdon Tube Pressure Transmitters***

The use of Bourdon tubes as pressure sensing elements makes it possible to construct an instrument which will measure absolute, differential, or gage pressures from as low as 50 to as high as 6500 psi. Pressure transducers of this type minimize the effects of vibration and acceleration, since the tube is supported at the center of the periphery—resulting in a "bull-horn" appearance—and the two opposing sections of the tube are balanced by the potentiometer winding on one arm of the tube and by the wiper brush on the opposite arm. No linkage or gearing is necessary in this design, thus greatly reducing friction and removing backlash errors. Bourdon tube pressure transmitters can be made highly resistant to environmental vibration by oil filling the transducer case and applying pressure by a suitable flexible diaphragm, thus effectively isolating the transducer mechanism from the fluid whose pressure is being measured. By the appropriate use of corrosion-resistant parts, the oil-filled instrument can also be made resistant to acids such as red fuming nitric acid, or to oxidizers such as hydrogen peroxide.

***Capsule-Type Pressure Transmitters***

Capsule-type pressure sensing elements are used in low pressure Giannini instruments to measure absolute, differential, or gage pressures ranging from 5 to 50 psi. For optimum performance under vibration and acceleration, the capsule in a typical Giannini pressure transducer is connected to a rocker arm by means of a flexure pivot. The rocker arm is in turn supported by other flexure pivots and is provided with a counterweight at one end. The wiper brush is connected to the opposite end of the rocker arm and sweeps the potentiometer winding, which is mounted on the instrument frame. This type of construction provides for a balanced instrument and also gives a mechanical advantage, resulting in increased resolution.

## Advantages and Limitations of Resistance Output-Type Transducers

Sensitivity of a potentiometer output transducer is dictated by the number of turns of wire that can be wound on the resistance element. Thus, limited resolution is the major disadvantage of this type of instrumentation. However, improved techniques make it possible to sweep as many as 1500 wires, thus providing a relatively high resolution of 0.07 per cent.

The outstanding advantage in resistance-type transducers is the comparatively large voltage output. For example, electrical outputs as high as 50 volts are common. This makes it possible to eliminate some or all stages of amplification, the amplifiers necessary for those stages, and the drift and other deficiencies associated with electronic equipment. The instruments are small in size and weight, which, in addition to the lesser amount of associated electronic equipment required, makes for ideal aircraft or missile telemetering or control applications.

Two or more electrical outputs can be provided from one pressure sensing element. Special functions can be produced, such as output linear with altitude, density, or with airspeed. Potentiometers may be provided with taps which result in numerous possibilities from a design standpoint. Potentiometer outputs can be combined to produce one output which accomplishes partially the computation utilized in a system. Typical examples are seen in Giannini Mach number and true airspeed devices. All of these characteristics serve to make a pressure transducer containing rheostat or potentiometer outputs an extremely versatile instrument suitable for many specialized applications.

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